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THESIS

SUSTAINABLE DEVELOPMENT: A STRATEGY FOR REGAINING CONTROL OF NORTHERN MALI

by

Benjamin M. Symonette

June 2014

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SUSTAINABLE DEVELOPMENT: A STRATEGY FOR REGAINING CONTROL OF NORTHERN MALI

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ABSTRACT

This thesis proposes a decision-support process to facilitate a more comprehensive approach that U.S. Africa Command (AFRICOM) may adopt to reclaim control of Northern Mali from violent extremist organizations (VEOs). Specifically, the thesis explores the effectiveness of intervening with sustainable-development projects to deter, displace, or defeat VEOs. The author defines the problem through a systems approach by investigating the conditions that contribute to the Malian government's lack of control, then uses a design approach to identify an intervention strategy. After prototyping possible solutions, the author explores U.S. policy and strategy to verify the feasibility of intervening via sustainable development initiatives. Finally, the author uses integer programming (IP) to formulate, solve, and interpret the intervention strategy. The author evaluates two IP models to allocate sustainable-development projects optimally for the purposes of rehabilitating desert lands, gaining compliance from non-state actors, and regaining control of ungoverned territories. This research finds that using a decision-support process may help AFRICOM nest its strategy within the policy promoted by the U.S. ambassador to Mali. By doing so, AFRICOM may gain more influence in Northern Mali by pursuing a "whole of government" approach.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACAS	Association of Concerned African Scholars
ACOTA	African Contingency Operations and Training Assistance
ACRI	African Crisis Response Initiative
AFRICOM	U.S. Africa Command
AK	Avtomat Kalashnikova
AQIM	Al–Qaida in the Islamic Maghreb
AOR	area of responsibility
AU	African Union
BIP	binary integer linear programming
CBA	cost–benefit analysis
COA	course of action
COCOM	combatant command
CNRDR	National Committee for the Restoration of Democracy and State
CT	counterterrorism
DIMEFIL	diplomatic, information, military, economic, financial, intelligence, and law enforcement
DOD	U.S. Department of Defense
DODD	U.S. DOD directive
DOS	U.S. Department of State
ECOWAS	Economic Community of the West African States
GSPC	Salafist Group for Preaching and Combat
IGO	International Governmental Organization
IMET	International Military Education and Training
IO	international organization
JP	joint publication
JSOTF–TS	Joint Special Operations Task Force—Trans Sahara
LP	linear programming
NATO	North Atlantic Treaty Organization
NDS	National Defense Strategy
NMS	National Military Strategy

NGO	nongovernmental organization
NSA	non–state actor
NSS	National Security Strategy
OCONUS	outside the continental U.S.
OEF–TS	Operation Enduring Freedom—Trans Sahara
OOTW	operations other than war
OSC	Office of Security Cooperation
OUSD(P)	Office of the Under Secretary of Defense for Policy
PBO	peace building operations
PMESII–PT	political, military, economic, social, information, infrastructure, physical environment and time
PSI	Pan Sahel Initiative
QDDR	Quadrennial Diplomacy and Development Review
QDR	Quadrennial Defense Review
ROMO	range of military operations
S–AF	U.S Department of State Bureau of African Affairs
S–NEA	U.S Department of State Bureau of Near Eastern Affairs
SFA	Security Force Assistance
SOCAFRICA	U.S. Special Operations Command Africa
SSTR	stability, security, transition, and reconstruction
TSCP	Theater Security Cooperation Programs
TSCTI	Trans–Saharan Counterterrorism Initiative
TSCTP	Trans–Sahara Counterterrorism Partnership
UN	United Nations
U.S.	United States
USAID	U.S. Agency for International Development
VEO	violent extremist organizations

French / Malian Acronyms

ADEMA	*Alliance pour la Démocratie en Mali*
AJM	*Association des Jurists Maliennes*
AMUPI	*Association Malienne pour l'Unité et le Progrès de l'Islam*
ATT	*Amadou Toumani Touré*
DSM	*direction de la sécurité militaire*
DTTA	*Direction des Transmissions et des Télécommunication des Armées*
ETIA	*Echelon Tactique Inter–Armée*
FAM	*Forces Armées du Mali*
FIAA	*Front Islamique et Arabe de l'Azawad*
FLAA	*Front de Liberation de l'Air et l'Azawad*
FPLA	*Front Populaire de Liberation de L'Azawad*
HCUA	*Haut Conseil pour l'unité de l'Azawad*
MNLA	*Mouvement National pour la Libération de l'Azawad*
MUJAO	*Mouvement pour l'Unicité et le Jihad en Afrique de l'Ouest*
MFUA	*Mouvements et Fronts Unifiés de l'Azawad*
MPA	*Mouvement Populaire de l'Azawad*
PMT	*parti malien du travail*

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EXECUTIVE SUMMARY

Over the past decade, the Malian government has engaged in counterterrorism (CT) operations[1] that were initially successful. However, the government has focused on short-term remedies that may eventually fail (e.g., the annual Flintlock exercises and other CT programs in the trans-Sahara).[2] These fixes target symptoms; they do not address the root causes of the problem by establishing control over the ungoverned territories of Northern Mali. In addition, the Malian government has supported third-party interventions, such as French-led CT operations (as opposed to Malian- or West African-led military operations),[3] while attempting to serve its national interests by tolerating cronyism in key cities. These narrowly focused quick fixes have led to widespread feelings of disenfranchisement and marginalization among the people.[4] As a result, violent non-state actors (NSAs) continue to flout the government and destabilize the region, while the Malian government continues to apply "fixes that fail" that only serve to depress its nation-building capacities.

Since the establishment of U.S. Africa Command (AFRICOM) in 2007, U.S. military involvement in Northern Mali has been largely ineffectual. By focusing on CT

1 Counterterrorism (CT) operations are actions taken directly against terrorist networks and indirectly to influence and render global and regional environments inhospitable to terrorist networks. U.S. Department of Defense, *Department of Defense Dictionary of Military and Associated Terms* (Joint Publication 1–02) (Arlington, VA: Department of Defense, 2014), 60.

2 Since 2006, the annual Flintlock training exercises involved over 15 regional state-actors' militaries to maintain African partnerships and security apparatuses to deal with violent extremists and violent non-state actors. Like Flintlock, the U.S. Africa Command (AFRICOM) executed other CT programs through the Trans Sahara Counterterrorism Partnership (TSCTP).

3 End-run interventions refer to fixes that bypass the barriers fundamental to the original problem. For example, the U.S. allocated approximately $119 million in fiscal year 2013 to deal with drought issues and conflict affected Malians. Even as the largest donor of humanitarian aid, the U.S. failed to deal with the violent extremists operating in Northern Mali. Additionally, the French and U.S. used end-run interventions (i.e., direct CT operations and support to CT operations respectively), despite the potential diversion of aid to terrorist groups. Alexis Arieff, *Crisis in Mali* (CRS Report R42664) (Washington, DC: Congressional Research Service, 2013), https://www.fas.org/sgp/crs/row/R42664.pdf., 4.

4 Before the military coup in 2012, successive U.S. administrations and many nongovernment observers viewed Mali as a democratic success, despite governance challenges—particularly in Northern Mali—and indications that the Malian public increasingly resented perceived state corruption and cronyism. Mali has been a longtime recipient of U.S. development aid, with modest gains achieved by health, education, and food security programs. Developments throughout 2012 bring into question the effectiveness of these programs. Ibid., 4.

operations, AFRICOM has supported short-term strategies to solve symptoms, not problems. Nor has AFRICOM used an inclusive decision-support process to evaluate the benefits of such actions (e.g., supporting CT exercises, programs, and operations). In short, AFRICOM has not justified the costs of operating in Northern Mali. This thesis proposes a decision-support process that AFRICOM may use to guide engagement in Northern Mali and regain control of ungoverned political spaces. By ensuring that a given course of action is nested within American policy, AFRICOM's decision makers may garner more support from U.S. policymakers who do not favor military intervention in Mali (save for a few limited action concerning intelligence and logistics).

The decision-support process reveals that AFRICOM is facing a "wicked problem,"[5] in which decision makers offer competing solutions that are diametrically opposed and constraints are continuously changing. In the first step of the proposed decision-support process, the author uses a systems approach to investigate the conditions and variables that contribute to loss of control over ungoverned spaces and identifies a suitable long-term strategy. The fundamental problem lies in how to marginalize and disenfranchise dissident NSAs in Northern Mali, many of whom do not comply with the government, which has ceded control to violent extremist organizations (VEOs) in some places. AFRICOM must determine a long-term strategy that persuades NSAs to support the Malian government's efforts to deter, displace, and defeat VEOs.

The second step of the proposed decision-support process employs design thinking to identify courses of action. The design approach is a methodical, problem-solving method for analysts to develop innovative solutions and create prototypes. Using the design approach, the author identifies sustainable development as a suitable approach for Northern Mali.

[5] The literature suggests that a problem is truly wicked if it contains the following characteristics: (1) no agreement about the formulation of the problem; (2) no agreement on competing solutions (none of which have stopping rules to determine when the problem is solved); and (3) the complexity of the problem solving process grows out of control due to constantly shifting constraints. Jeff Conklin, *Wicked Problems & Social Complexity* (Napa, CA: CogNexus Institute, 2006); Russell L. Ackoff and Sheldon Rovin, *Redesigning Society* (Palo Alto, CA: Stanford University Press, 2003); Nancy Roberts, "Wicked Problems and Network Approaches to Resolution," *International Public Management Review* 1, no. 1 (2000), 1–19; Horst W. J. Rittel and Melvin M. Webber, "Dilemmas in a General Theory of Planning," *Policy Sciences* 4, no. 2 (1973): 155–169.

After defining the problem and solution, the author explores U.S. policy and strategy documents to verify the feasibility of pursuing sustainable-development projects. According to policy documents, sustainable development activities are acceptable to policymakers and the U.S. ambassador to Mali would likely approve them as well. Otherwise, by supporting the direct approach (that is, conducting counterterrorist operations), AFRICOM may continue to be perceived by the U.S. ambassador as an uncooperative player attempting to militarize U.S. policy there.

Finally, the author compares the results of two integer-programming (IP) models that formulate, solve, and interpret the proposed solution via quantitative methods, identifying the optimal implementations of sustainable development in Northern Mali. Assuming that input is derived from key stakeholders and data are thoroughly vetted, decision analysts can use this method to recommend an optimal allocation of sustainable-development projects, based on rehabilitation metrics from each district (or commune)—for example, metrics reflecting the degradation of desert lands or level of threat from VEOs. The equation behind the rehabilitation scores allows the decision analyst to rate communes according to multiple factors, such as sustainable development indicators, terrorist activities, criminal activities, and threat information. Ultimately, this step in the decision-support process justifies the strategy of using sustainable development to combat terrorism and degradation of the desert environment ("desertification") and substantiates various contributions to Mali's nation-building efforts.

This mixed-methods approach determines an optimal allocation of sustainable-development projects implemented to regain control of Northern Mali. In particular, the IP model allocates the following four types of projects to key locations to halt desertification and exert control over ungoverned spaces. Appendix C adds further detail.

Project Design 1, the analyst assumes the following:

1. Department of State (DOS)-led projects focus strongly on sustainable development; control is determined by the populace's compliance with the government.
2. The degree to which the government can maintain a permissive to uncertain environment is low,[6] as is its ability to maintain a low VEO threat level.
3. Zero to negligible use of external security/military forces (e.g., French and U.S.) is desired; instead, the indigenous security apparatus polices itself.

For Project Design 2, the analyst assumes the following:

1. DOS-led projects focus strongly on sustainable development; control is determined by the populace's compliance with the government.
2. The degree to which the government can maintain a permissive to uncertain environment is low,[7] as is its ability to maintain a low VEO threat level.
3. Minimal use of external security/military forces (e.g., French and U.S.) is desired; instead, the indigenous security apparatus polices itself.

For Project Design 3, the analyst assumes the following:

1. DOD- and DOS-led projects focus moderately on development.
2. The hostility in the environment is uncertain; the VEO threat is moderate to high.
3. Moderate use of external security or military forces (e.g., Economic Community of the West African States [ECOWAS]) is desirable.

For Project Design 4, the analyst assumes the following:

1. DOD-led projects focus moderately on development.
2. The environment is hostile; VEO threat is high.
3. Overt employment of security and military forces (e.g., Malian Defense Forces, ECOWAS, French, coalition support) is desirable.

[6] The level of permissiveness in a commune is determined by assessing the operational environment, which is a composite of the conditions, circumstances, and influences that affect the employment of military forces and bear on the decisions of the unit commander. A permissive environment suggests the host country military and law enforcement agencies have control and the intent and capability to assist operations that a unit intends to conduct. An uncertain environment suggests the host government forces, whether opposed to or receptive to operations that a unit intends to conduct, do not have totally effective control of the territory and population in the intended area of operations. A hostile environment suggests the hostile forces have control and the intent and capability to effectively oppose or react to the operations a unit intends to conduct. U.S. Department of Defense, *Joint Publication 1–02*, 203.

[7] Ibid., 273.

Each IP model represents a course of action (COA) that AFRICOM could pursue. See Chapter VII for a COA comparison. For COA I, Model I allocates 24 projects, which consist of four project-design types (see Appendix C, Section D) and achieve the following:

1. Model I allocates 24 projects to regain control of 65.7 percent of ungoverned territory.
2. Model I rehabilitates desertified land with a 71.9 percent increase in land quality.
3. The strength in this COA is its ability to provide reasonable coverage throughout Northern Mali. In particular, Model I controls Tombouctou significantly better than Model II.

For COA II, Model II allocates 24 projects and regains control of 45.5 percent of ungoverned territory (20.2 percent less than COA I), and rehabilitates desertified land with a 68.5 percent increase in land quality. Ultimately, Model I generates a more optimal solution than Model II.

Although only 24 of 47 communes (or districts) receive a project, the author compares two COAs that use an indirect approach to target VEOs in ways that may satisfy the U.S. ambassador and AFRICOM commander without endangering the indigenous population or the integrated country strategy. For example, as communes with a project draw in workers from other communes that were formerly VEO sanctuaries, the value of these places for hiding and regrouping decreases. Also, the jobs associated with sustainable development in one commune benefit other communes as employment in agriculture, infrastructure development, security, and other fields is shared.

Ultimately, AFRICOM should nest its strategy with the policy espoused by the U.S. ambassador to Mali (i.e., the ambassador's classified integrated country strategy). In doing so, AFRICOM may gain more influence in Northern Mali and achieve U.S. interests through a "whole of government" approach. This research develops a decision-support process with which to explore a long-term strategy characterized by sustainable development, for the benefit of AFRICOM strategies and programs.

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I. INTRODUCTION

A. PREFACE

U.S. decision makers are looking for stable footings on which to ground a redefinition of America's role in the world arena, while carefully employing military forces across various regions of conflict. Ideally, strategic-decision makers and policy implementers pursue political objectives by integrating the instruments of national power, or "DIMEFIL" (i.e., diplomatic, informational, military, economic, financial, intelligence, and legal domains), toward a specific purpose. U.S. decision makers have a full panoply of DIMEFIL instruments to use across a spectrum from military operations to operations other than war (OOTW).[8] However, the global challenges of the twenty-first century have exposed the limitations of the U.S. national-security system in terms of how hard and soft powers are leveraged.[9] Because of the sheer magnitude of the national-security issues involved, this thesis limits its scope to the trans-Sahara (Sahel) region in Northern Mali. In doing so, the author hopes to emphasize the dangers of overreliance on "end runs"[10] (i.e., direct military action) to intervene in problems as complex or wicked as regaining control of Northern Mali.

[8] U.S. Department of Defense, *Department of Defense Dictionary of Military and Associated Terms* (Joint Publication 1–02) (Arlington, VA: Department of Defense, 2014), A-140.

[9] Hard power is the use of coercive force, which is typically leveraged by the military and economic elements of the DIMEFIL. From Mao Zedong to Niccolò Machiavelli, hard power is that aggressive use of force to influence the behaviors or interests of others. Conversely, soft power is just about everything else; however, soft power may be leveraged by all elements of the DIMEFIL. In Chapter II, soft power is referred to as neocortical warfare, which Szafranski would suggest that DIMEFIL elements should strive to modify the behavior of enemy organisms without destroying the organisms.

[10] End-runs are simply informal attempts to conduct evasive maneuvers to achieve desired end results. The Project for National Security Reform argued that at times "…end runs work as short-term fixes; other times, however, they produce debacles like the Iran–Contra fiasco." Project on National Security Reform, *Project on National Security Reform: Forging a New Shield* (Washington, DC: Project on National Security Reform, 2008), 29.

B. BACKGROUND OF NORTHERN MALI

Over the past decade, the Malian government has engaged in counterterrorism (CT) operations[11] that were initially successful. However, the government has focused on short-term remedies that may eventually fail (e.g., the annual Flintlock exercises and other CT programs in the Trans Sahara).[12] These fixes targeted symptoms; they do not address the root causes of the problem by controlling the ungoverned territories of Northern Mali. Additionally, the Malian government supported third party interventions, such as French-led CT operations (as opposed to Malian- or West African-led military operations),[13] while attempting to serve its national interests by tolerating cronyism in key cities. These narrowly focused quick fixes have led to widespread feelings of disenfranchisement and marginalization among the people.[14] As a result, violent non-state actors (NSAs) continue to flout the government and destabilize the region, while the Malian government continues to apply "fixes that fail," which only serve to depress its nation-building capacities.

In recent years, U.S. policymakers have identified Africa's natural resources, especially energy and violent NSAs, respectively, as the key opportunities and threats that are strategically significant to American national interests. Growing concerns for North Africa's numerous humanitarian crises and armed conflicts led Congress to create

11 Counterterrorism operations are actions taken directly against terrorist networks and indirectly to influence and render global and regional environments inhospitable to terrorist networks. U.S. Department of Defense, *Joint Publication 1–02*, 60.

12 Since 2006, the annual Flintlock training exercises involved over 15 regional state-actors' militaries to maintain African partnerships and security apparatuses to deal with violent extremists and violent non-state actors. Like Flintlock, the U.S. Africa Command (AFRICOM) executed other CT programs through the Trans Sahara Counterterrorism Partnership (TSCTP).

13 End-run interventions refer to fixes that bypass the barriers fundamental to the original problem. For example, the U.S. allocated approximately $119 million in fiscal year 2013 to deal with drought issues and conflict affected Malians. Even as the largest donor of humanitarian aid, the U.S. failed to deal with the violent extremists operating in Northern Mali. Additionally, the French and U.S. used end-run interventions (i.e., direct CT operations and support to CT operations respectively), despite the potential diversion of aid to terrorist groups. Arieff, *Crisis in Mali*, 4.

14 Before the military coup in 2012, successive U.S. administrations and many nongovernment observers viewed Mali as a democratic success, despite governance challenges—particularly in Northern Mali—and indications that the Malian public increasingly resented perceived state corruption and cronyism. Mali has been a longtime recipient of U.S. development aid, with modest gains achieved by health, education, and food security programs. Developments throughout 2012 bring into question the effectiveness of these programs. Ibid., 4.

a new military combatant command for Africa (AFRICOM) in 2007. Since decolonization in the 1960s,[15] state-actors have been slow to address threats in North Africa; however, they now react in crisis mode, hoping to avoid "weaker" NSAs' baited deterrence traps.[16]

The fundamental U.S. policy question for Northern Mali is how AFRICOM can work with the DOS and Malian government to deter, displace, and defeat VEOs and violent NSAs. The key problem that AFRICOM faces is the Malian government's lack of control over the Sahel's ungoverned spaces. By not controlling the Sahel, Mali allows violent NSAs to strengthen their networks and combat power and create support zones from which to attack U.S. interests. Meanwhile, because the VEOs oscillate in and out of terrorist mode,[17] the Malian government is always solving yesterday's problems.

Unconsciously, the Malian government operates under a "fixes that fail" framework, rather than developing networked coalitions and a collaborative strategy. Ultimately, the lack of control in the Sahel reflects Mali's inability to provide incentives

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[15] Fischer-Tiné gave an anthropological definition of post-colonialism as the relations between nations and areas they colonized and once ruled. Following post-colonialism, the newly formed African governments were left with the border conflicts haphazardly created by former European rulers. Since then, African nations and their allies have struggled with the ongoing conflicts (e.g., border disputes, education, slavery, and much more), which detract from the dire need for sustainable development. Harald Fischer-Tiné, "Postcolonial Studies," Institute of European History, accessed May 12, 2014, http://ieg–ego.eu/en/threads/europe–and–the–world/postcolonial–studies/harald–fischer–tine–postcolonial–studies#citation.

[16] Adler aptly warned that a deterrence trap is a "structural situation that leaves social actors with the dreadful choice of reacting with force to a provocation that elicits response or practicing appeasement." Emanuel Adler, "Complex Deterrence in the Asymmetric-Warfare Era," *Complex Deterrence: Strategy in the Global Age* edited by T.V. Paul, Patrick M. Morgan, and James J. Wirtz, Chicago, IL: The University of Chicago Press, 2009, 85–108.

[17] The phrase "oscillate in and out of terrorist mode" alludes to the al-Suri model. Chief al-Qaida strategist, Abu Mus'ab al-Suri, developed the al-manhaj model, which is a program that espouses the development of small, decentralized terrorist cells sprouting in hundreds of locations throughout the world. Arquilla described al-Suri's objective as a "…goal to build enough small cells so that no single cell has to mount an attack more than, say, once per year." He further explained that the cumulative effect of these small cells should "…achieve the desired terrorist drumbeat." Therefore, commensurate with the al-Suri model, VEOs and supporting violent NSAs would remain dormant, "…until the heat [is] off, then strike again in a year or so." Arquilla added that al-Suri's limited scale of attacks conducted by these cells will cause "…disproportionate psychological trauma and one day achieve massive cumulative material effects." John Arquilla, "Small Cells Vs. Big Data," *Foreign Policy,* April 22, 2013; Jim Lacey, *A Terrorist's Call to Global Jihad: Deciphering Abu Musab Al-Suri's Islamic Jihad Manifesto* (Annapolis, MD: Naval Institute Press, 2008).

for negotiation with the NSAs. Sustainable-development programs may provide a bargaining chip to help the Malian government negotiate for compliance and stability in the region.[18]

C. PURPOSE AND SCOPE

The purpose of this thesis is to demonstrate the efficacy of using a proposed decision-support process to inform AFRICOM decision makers as they deal with highly complex problems. By relying on qualitative and quantitative inputs to problems, AFRICOM may increase its influence over the problem set in Northern Mali. This thesis leverages systems and design thinking to frame a problem, identify coping strategies, and identify a point of intervention. Given the persistence of small wars throughout North Africa, this thesis explores also the strategic utility of using quantitative modeling to identify decision strategies for deterring, displacing, disrupting, and targeting violent extremist organizations (VEOs) and violent non-state actors (NSAs).

While the implications are far reaching, the scope of this thesis is confined to analysis and recommendations for the wicked problem of Northern Mali. This research is designed specifically to investigate the usefulness of decision modeling[19] in quantifying a

[18] Throughout this thesis, the author refers to sustainable development in the context of "combating desertification," which includes activities that are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development which are aimed at the following: (a) prevention and/or reduction of land degradation; (b) rehabilitation of partly degraded land; and (c) reclamation of desertified land. Therefore, sustainable development represents desirable future state for the carrying capacity of natural systems with the socioeconomic challenges faced by human societies. In particular, sustainable development includes the concern for humanity, future generations, living conditions, and use of resources, without undermining the sustainability of the environment and natural systems. United Nations Convention to Combat Desertification, "Desertification: The Invisible Frontline," *UNCCD Publications* (23 January 2014, 2014). http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/Desertification_The%20invisible_frontline.pdf.

[19] Decision modeling is a scientific approach to operationalize a real-world problem with the intent to facilitate the decision making process.

recommended strategy. Since the problems in North Africa tend to yield low-intensity conflicts,[20] decision analysts currently rely on information dominance to inform their recommendations.[21]

D. RESEARCH QUESTIONS

This research treats the following fundamental question: Would AFRICOM gain more influence with policymakers if its development projects in Northern Mali were informed by analysis that can predict efficacy in regaining the ungoverned territories? In responding to the primary research question, the author addresses the following subordinate questions:

1. Do sustainable-development projects increase the compliance of NSAs and eventual displacement of VEOs?
2. What are the benefits of investing in development to support theater campaign plans, economic development, and indigenous security forces?
3. How can sustainable development help build capacity to strengthen African partner nations?
4. What is the efficacy of using systems and design thinking to identify problems, intervention points, and the residual effects of decision making?
5. Is there strategic advantage in decision analysts' using both qualitative and quantitative analyses to inform decision makers?

E. METHODOLOGY

Overall, this research uses a mixed-methods approach towards the problem and follows a decision-support process with the following components:

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[20] According to FM 100–20/AFP 3–20, low-intensity conflict (LIC) is a political–military confrontation between contending states or groups below conventional war and above the routine, peaceful competition among states. It frequently involves protracted struggles of competing principles and ideologies. LIC ranges from subversion to the use of armed force. It is waged by a combination of means, employing political, economic, informational, and military instruments. LIC are often localized, generally in the undeveloped countries, but contain regional and global security implications. Given the definition of LIC, let high intensity conflict be just about everything else. U.S. Army and U.S. Air Force, *Military Operations in Low Intensity Conflict* (Field Manual 100–20 / Air Force Pamphlet 3–20) (Arlington, VA: U.S. Army and U.S. Air Force, 1990), 1.1–1.7.

[21] Arquilla applied a systems approach to focus the application of power generated by "information dominance." Arquilla aptly explained that information dominance consists of "knowing everything about an adversary while keeping the adversary from knowing much about oneself." Therefore, as the U.S. operates in Africa, it must decisively enhance its strengths while debilitating its opponents. John Arquilla, "The Strategic Implications of Information Dominance," *Strategic Review* 22, no. 3 (1994), 24–30, 25.

1. A systems approach to frame the problem (Step I)
2. A design approach to identify an intervention (Step II-A)
3. An evaluation of policy and strategy to identify limitations (Step II-B)
4. Use of integer programming (IP) to model the problem (Steps III and IV)

For the first step, this research employs a qualitative method (i.e., systems thinking) to investigate the conditions and variables that allowed VEOs and violent NSAs to gain control of the region. This systems approach allows the identification of a point of intervention and a suitable long-term strategy. The second step of the decision support process applies design thinking to identify an intervention. The design approach is a methodical problem-solving method that allows the decision analyst to develop prototypes of innovative interventions. After defining the problem and solution, this thesis explores U.S. policy and strategy documents to assess the feasibility of intervening with sustainable-development projects. Finally, an IP to formulate, solve, and interpret interventions is demonstrated. IP modeling is a quantitative method for modeling the implementation of sustainable development in Northern Mali.

F. SUMMARY OF FINDINGS

The systems approach identifies AFRICOM's continual use of short-term fixes, which cause unintended consequences: for example, military intervention has encouraged violent NSAs to cede control of ungoverned territories to VEOs. Additionally, the systems approach identifies sustainable development as an intervention with feasible long-term prospects of rehabilitating desertified rural areas, increasing employment, and regaining control of the political space. Focusing on a long-term strategy is expected to mitigate the unintended consequences brought on by quick fixes. Assuming AFRICOM refocuses its support to sustainable development, the design approach will allow the analyst to develop prototypes of sustainable-development projects in Northern Mali.

After numerous trials of prototyping during this research, four sustainable development-project designs (P_1, P_2, P_3, and P_4) merged. These designs account for DOS-led versus DOD-led sustainable development, as well as the various levels of threat and land degradation across Northern Mali. The third and fourth steps of the decision-support process identify IP as an acceptable method of operationalizing the problem.

Overall, this mixed-methods approach determines an optimal allocation of sustainable-development projects aimed at regaining control of Northern Mali. In particular, the model allocates projects to key locations to combat desertification and control ungoverned spaces. Finally, each IP model represented a course of action (COA) that AFRICOM could pursue:

COA I: Model I allocates 24 projects, which consist of four project-design types (P_1, P_2, P_3, and P_4) and achieves the following:

1. Model I allocates 24 projects to regain control of 65.7 percent of ungoverned territory.
2. Model I rehabilitates desertified land with a 71.9 percent increase in land quality.
3. The strength in this COA is its ability to provide a reasonable amount of coverage throughout Northern Mali. In particular, Model I controls Tombouctou significantly better than Model II.

COA II: Model II allocates 24 projects, which consist of four project-design types. Model II regains control of 45.5 percent of ungoverned territory (20.2 percent less than COA I), and rehabilitates desertified land with a 68.5 percent increase in land quality.

Although only 24 of 47 communes (or districts) “received” a project in this virtual allocation, the IP models operate under the assumption that the Department of State (DOS) and Department of Defense (DOD) will use an indirect approach to target VEOs in ways that satisfy the U.S. ambassador and the AFRICOM commander without putting the indigenous population or the integrated country strategy at risk. For example, communes with a project would draw in workers from other communes to deny VEOs sanctuaries from which to hide and regroup.

G. THESIS ROADMAP

Chapter II of this thesis summarizes decision-modeling techniques and demonstrates integer programming’s capabilities in modeling conflicts. Chapter III presents the first step in the proposed decision-support process, explaining the systems approach as a way to frame problems and proposing the design approach to identify an intervention based on sustainable development. Chapter IV examines U.S. policies and strategies to verify sustainable development as consistent with U.S. objectives and interests. Chapter V details the fourth step in the decision support process, integer programming. Chapter VI uses a type of integer programming (i.e., binary integer programming or BIP) to model two COAs for the conflict in Northern Mali. Chapter VII analyzes and synthesizes the model inputs and outputs and presents an analysis to determine how sensitive the optimal solution is to changes in threat conditions, available resources, and land and other development factors. Chapter VIII provides conclusions and recommendations for future research. Appendices A, B, and C further explain the major concepts of systems and design thinking, while appendices D, E, F, and G provide information regarding the input variables in the BIP model. Appendix H illustrates the set-up for Model I and Model II in Frontline Systems' Risk-Solver Platform (RSP) add-in tool. Appendix I explains the inspiration behind the constraints in the two BIP models, and Appendix J provides an abridged history of Northern Mali for those not familiar with the problem set. Finally, in Appendix K, the author illustrates a recent direct approach (counterterrorism operations), which is the current military strategy of AFRICOM in Northern Mali.

II. ABOUT INTEGER PROGRAMMING

This chapter provides a background on integer programming (Step IV) before launching into the decision-support analytic process. The ability to model real-world scenarios is especially vital as U.S. decision makers deal with the small-war conflicts of the twenty-first century.[22] While quantitative modeling techniques can help to cope with complex problems, decision analysts must be cautious of the limitations, assumptions, and applicability of this modeling approach. Any quantitative approaches used to model scenarios and identify optimal courses of action should remain flexible, economical, widely acceptable, and relatively simple to adapt.

A. DECISION MODELING

Since Frederick W. Taylor pioneered the "principles of the scientific approach to management" in the early 1900s and the military's successful use of these developments in World War II, various industries have employed similar techniques in managerial decision-making and planning,[23] and decision modeling continues to shape the battlefield. Decision modeling operationalizes real-world problems to facilitate the decision-making process. While decision analysts from various backgrounds may refer to decision modeling as quantitative analysis, management science, or operations research,[24] this thesis adopts the term "decision modeling," because the analysts in this scenario leverage the model in an executive decision-making context. With this aim of influencing decision makers, this chapter supplies context to Step IV in the framework for decision-maker support.

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[22] The term operationalize refers to the notion of modeling a phenomenon that may not be directly quantifiable. Therefore, the author proposes a "decision support framework" to define abstract concepts to lend more clarity to theoretical concepts. Furthermore, decision analysts can define what issues are within scope for the model and what is out of scope.

[23] Nagrai Balakrishnan, Barry Render, and Ralph M. Stair, *Managerial Decision Modeling with Spreadsheets* (Upper Saddle River, NJ: Pearson/Prentice Hall, 2007), 2.

[24] Ibid., 2.

B. DETERMINISTIC MODELING

To analyze a problem by treating a yield as a random variable, a decision analyst requires the use of complicated stochastic (or probabilistic) programming models; however, analysts normally use a deterministic model, in which the random variables in the yield function are replaced by either their most likely values or expected values.[25] Whether analysts choose to operationalize a conflict with probabilistic or deterministic modeling techniques, they must understand the risks, levels of certainty and uncertainty, and assumptions. Determining the correct actions to take during a conflict can be quite difficult; therefore, this research relies on deterministic modeling as the starting point for solving an enduring problem. An envoy of facilitators cannot go into negotiations without proper preparation and thoughtful recommendations, and certainly an executive decision maker should never make decisions without proper information.

Through deterministic modeling, decision analysts gather relevant input-data values that exhibit certainty. To determine an appropriate level of sustainable development, analysts require data sets of known, fixed resources to use in selecting the best sites for sustainable development in conflict regions. Analysts can determine the specific amounts of resources needed to establish a development, based on project and environmental design specifications (e.g., population density, water resources, water-table levels, land arability, and precipitation). In addition, analysts can determine the net benefits or profit contributions of their proposed sustainable-development operations.

C. MATHEMATICAL MODELING

Mathematical programming is a widely acclaimed decision-modeling technique that assists the decision analyst in offering recommendations to decision makers by identifying an optimal course of action. Although several optimal choices may exist, through mathematical programming the decision maker can make an informed choice out

[25] Katta G. Murty, *Operations Research: Deterministic Optimization Models* (Upper Saddle River, NJ: Prentice Hall, 1994), 9.

of many possible decisions or combinations of choices, all other things being equal.[26] What sets decision modeling apart from other modeling techniques is that the models are sets of mathematical relationships, which analysts express as equations and inequalities. To prototype a mathematical model, this research uses Microsoft Excel spreadsheets to analyze computations (see Appendix H). Although software-modeling packages are useful, analysts and decision makers do not require sophisticated mathematical ability, and basic algebra is used in this thesis.

D. LINEAR PROGRAMMING

This section focuses on the assumptions behind Step IV as regards formulation, solution, and interpretation. Figure 1 illustrates the fourth step of the overall decision-support process.

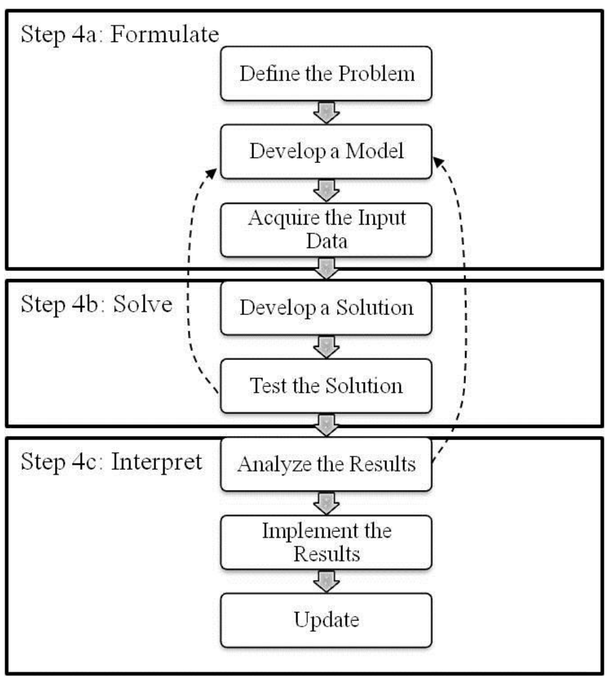

Figure 1. Step IV—A Decision-Modeling Approach[27]

[26] John W. Carroll, "Natural Laws in Scientific Practice," *Philosophy and Phenomenological Research* 71, no. 1 (2005): 240–245, doi:10.1111/j.1933–1592.2005.tb00446.x. In other words, ceteris paribus acknowledges that the mathematical programming model can fail due to intervening factors; however, this scientific assumption allows the analyst to filter factors.

[27] Balakrishnan, Render, and Stair, *Managerial Decision Modeling with Spreadsheets*, 5.

A widely used optimization technique, linear programming (LP) allows decision analysts to determine feasible plans, which are optimal with respect to a certain agreed-upon linear-objective function. In particular, it determines a plan that maximizes or minimizes some linear function over all possible feasible plans.[28] For Northern Mali, analysts can plausibly support decision makers through George D. Dantzig's development of simplex algorithms, which are the mathematical formulation of LP models and simple optimization algorithms.[29] Ultimately, LP involves the selection of activities to obtain an optimal program or plan. In general, this thesis uses an evaluation function that is subject to multiple constraints (see Chapter VI).

Since the complex problems of the twenty-first century are difficult to approach expeditiously by hand, decision analysts rely on technology for assistance. This research uses simple spreadsheet-based applications to help decision analysts develop advanced LP methods that accommodate varying levels of complexity. The programming model presented relies heavily on Microsoft Excel with advanced solver add-ins.

1. Basic Assumptions

Should decision analysts choose the deterministic modeling approach, they must reevaluate the realism of leveraging LP. In general, analysts can logically use LP when the following four assumptions hold: certainty, proportionality, additivity, and divisibility.

First, in relying on data characterized by certainty (i.e., census reports and sustainable-development statistics[30]), the literature supports the assumption that LP models can serve as an initial platform from which to amend the model after negotiation meetings, site surveys, and refinements to information and intelligence gathering. The

[28] Vincent A. Sposito, *Linear and Nonlinear Programming*, 1st ed (Ames, IA: Iowa State University Press, 1975), 8–9.

[29] Balakrishnan, Render, and Stair, *Managerial Decision Modeling with Spreadsheets*, 20.

[30] United Nations, *2012 FAO Statistical Yearbook: Chapter 4—Sustainability Dimensions* (Rome, Italy: FAO of the UN, 2012); City Population, "Population Statistics for Countries, Administrative Areas, Cities and Agglomerations—Interactive Maps—Charts," City Population, accessed May 05, 2014, http://www.citypopulation.de/Mali.html; The World Bank Group, "World Bank Climate Variability Tool," World Bank, accessed May 05, 2014, http://sdwebx.worldbank.org/climateportalb/home.cfm?page=country_profile&CCode=MLI.

values used to derive the objective function and constraints are known with certainty and remain static throughout the application of the model. A static model involves determining an optimum solution for a one-period problem. Therefore, with each phase of the negotiations process, decision analysts continually update the LP model and sensitivity analysis. With each update, analysts should verify the underlying assumptions of certainty, which requires that responses to variable values be exactly equal to the responses represented by the coefficients.

Second, the LP model operates under the assumption that proportionality exists in the objective function and constraints. For example, if the establishment of one small sustainable project consists of digging three wells, then three projects should yield nine wells.

The third assumption, additivity, means that the total quantity of sustainable-development projects should equal the sum of the individual activities. Therefore, the objective function will minimize or maximize the total quantity of projects.

Divisibility, the fourth assumption, allows decision variables to be fractions. In some cases, the decision analyst may not want a solution to take the form of a fraction.

The decision variables (or choice variables) are the unknown entities in a problem, which the decision analyst must solve to find values. Commensurate with any decision-modeling to assist leaders dealing with Northern Mali, the analyst should express the decision variables in simple alphanumeric symbols (e.g., x_{ij}).

2. Linear-Programming Properties

The first LP property is the optimization function, also known as the criterion or objective function, which represents some goal in a problem set. For example, an LP model allows the decision analyst to allocate projects across various locations in Northern Mali, based on rehabilitation scores, to target VEOs and violent NSAs. In this case, the objective is to maximize the total amount of rehabilitation in Northern Mali.

The second LP property deals with constraints, which limit the degree to which decision analysts can achieve a proposed objective. For example, in the selection of some number of sustainable-development projects, the analyst must ensure that the minimization or maximization of the objective is subject to limited resources (or constraints). This research considers the constraints of supply, demand, adjacency (or set covering), binary restrictions, and non-negativity. The constraints property is perhaps the most powerful and flexible aspect of the model, because it allows the analyst to mimic the conditions peculiar to a particular problem set. The model is limited to the imagination of the analyst (see Appendix J) and the clarity with which the decision maker provides guidance and restrictions. By expressing independent or dependent constraints as mathematical equations or inequalities, the analyst can mold the model to a particular situation.

Much of the power behind LP modeling comes from its third property: the ability to determine alternative courses of action. The LP models in this research allow decision makers to optimally select, reject, and allocate limited resources.

The fourth property of linear mathematical relationships allows the decision analyst to express a problem in terms of linear inequalities or equations; for the objective function and constraints, the LP model expresses the equations as first-degree linear functions. The capacity to express constraints as linear equations or inequalities provides flexibility in adapting the LP model to various situations.

E. INTEGER PROGRAMMING

Another form of linear programming, known as integer programming (IP), solves problems that require all variables to yield non-negative, integer values. These values represent a special case of discrete valued variables, which the decision analyst restricts to assuming a value from a specified discrete set.[31] In general, analysts can leverage pure IP, mixed IP, pure BIP, and mixed BIP.

With pure IP modeling, every decision variable must have an integer solution. For example, in recommending a total maximum quantity of sustainable-development projects to optimally control political space, decision analysts cannot recommend that

[31] Murty, *Operations Research: Deterministic Optimization Models*, 5.

23.5 sites receive a project. Instead, they create IP modeling constraints that force them to assign an integer value of 23 or 24. By rounding the LP solution, the analyst might not yield an optimal IP solution, and the IP objective function value is typically less optimal than the LP value. By contrast, mixed-IP modeling does not require that all decision variables yield integer solutions, and with mixed BIP, the analyst can model the problem to allow some decision variables to be binary, general integer, or continuous values. The model presented in this thesis is a pure BIP model, which dictates that all decision variables be binary (i.e., the solution set yield a value of 0 or 1).

III. PART I–THE DECISION-SUPPORT PROCESS: A QUALITATIVE REVIEW–A

This chapter focuses on two qualitative approaches to solving the problem of control over Northern Mali, covering the following steps:

1. A systems approach to frame the problem (Step I)
2. A design approach to identify a solution (Step II-A)

Figure 2 illustrates the overall decision-support process.

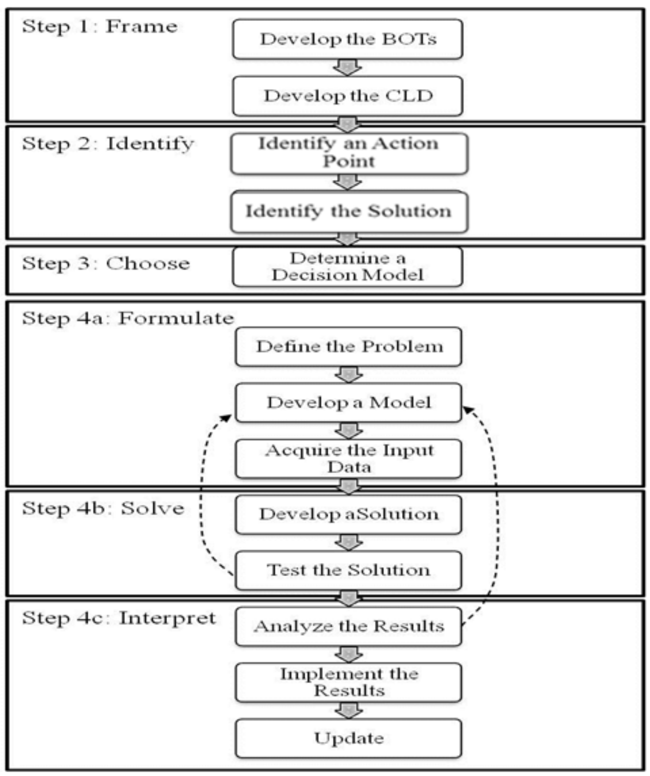

Figure 2. A Framework to Support Decision Makers[32]

Using qualitative analysis, an analyst can frame and identify the conditions and variables that led to the government's loss of control in Northern Mali. The problem set has many uncertain qualitative factors, especially in the initial formulation of the

[32] Balakrishnan, Render, and Stair, *Managerial Decision Modeling with Spreadsheets*, 5. The author adapted Balakrishnan, Render, and Stair's decision modeling approach, by adding Steps I to III: identify, choose, formulate.

problem. The analyst may run into difficulties with defining the problem, developing a model, acquiring input data, developing a solution, testing the solution, analyzing the results, and more.[33] Therefore, this thesis promotes systems and design thinking to frame the problem, identify an intervention point, and prototype the intervention. After applying qualitative approaches to a problem, an analyst can justifiably use quantitative analysis or program modeling to offer a solution.

A. STEP I-A. FRAME: A PRIMER

The situation in Northern Mali is wicked: that is, there is (1) no agreement about the formulation of the problem; (2) no agreement on competing solutions (none of which have stopping rules to determine when the problem is solved); and (3) the complexity of problem solving spins out of control due to constantly shifting constraints.[34] Churchman uses "wicked problems" to describe those that are "…difficult to solve because of incomplete, contradictory information and design parameters."[35] Ritell and Webber further refine the term to describe problems that cannot be definitively described or definitively and objectively answered.[36]

In Appendix A, the author discusses the nature of the changing constraints in Mali, as negotiators and other facilitators mediate between many parties who come and go, change their minds, fail to communicate, or otherwise change the rules by which the problem might be solved.[37] This thesis asserts that the Malian government is dealing with a wicked problem in Northern Mali, and the suggestions for coping and regaining control

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33 Ibid., 13–15.

34 Jeff Conklin, *Wicked Problems & Social Complexity* (Napa, CA: CogNexus Institute, 2006); Russell L. Ackoff and Sheldon Rovin, *Redesigning Society* (Palo Alto, CA: Stanford University Press, 2003); Nancy Roberts, "Wicked Problems and Network Approaches to Resolution," *International Public Management Review* 1, no. 1 (2000), 1–19; Horst WJ Rittel and Melvin M. Webber, "Dilemmas in a General Theory of Planning," *Policy Sciences* 4, no. 2 (1973), 155–169.

35 Charles West Churchman, "Guest Editorial: Wicked Problems," *Management Science* 14, no. 4 (1967).

36 Nancy Roberts, "Tackling Wicked Problems in Indonesia: A Bottom-Up Design Approach to Reducing Crime and Corruption," (2012), http://hdl.handle.net/10945/34423, 1–2; Rittel and Webber, *Dilemmas in a General Theory of Planning*, 155–169.

37 Nancy Roberts, "Coping with Wicked Problems: The Case of Afghanistan," *Research in Public Policy Analysis and Management* 11 (2001), 353–375.

are based on that framing of the situation. Identification of Northern Mali’s problems as wicked justifies the use of the decision-support process in Figure 2.

B. STEP I-B. FRAME: SYSTEMS APPROACH

Step I continues the procedure for framing the problem by applying the systems approach. Figure 3 illustrates how the systems approach feeds into the design approach and decision modeling.

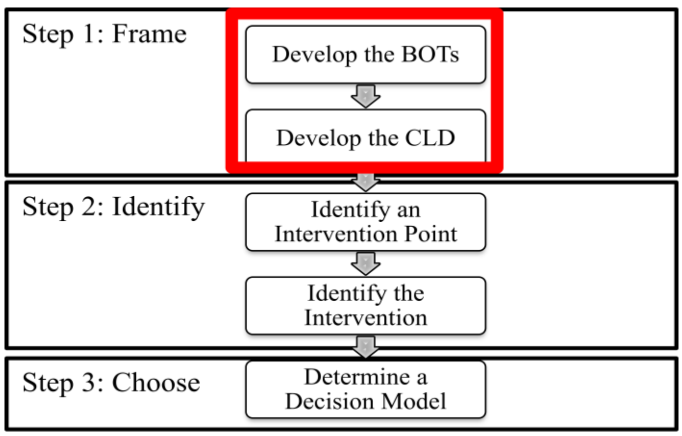

Figure 3. Step I—Frame: A Systems Approach

Key terms associated with the systems approach are highlighted in Table 1.

Table 1. Coping with Wicked Problems: the Systems Approach

Terms	Attributes	Definitions
Step I: Frame Systems Approach	Behavior over time (BOT) Causal loop diagram (CLD) Polarity (positive and negative)	The systems approach encompasses a large, amorphous body of methods, tools, and principles, all oriented to look at the interrelatedness of positive and negative forces, and seeing them as part of a common process.[38] Also, it represents the fifth discipline, which integrates with Senge’s other four disciplines: (1) personal mastery (2) mental models, (3) building a shared vision, and (4) team learning.[39]

[38] Peter M. Senge, *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization* (New York: Random House, 1994), 89.

[39] Ibid., 89.

In applying a systems approach to framing the Malian problem, the decision analyst should first consider behavior over time (BOT) diagrams to clarify the nonlinear, interrelated behavior of variables. Although the BOT diagrams devised for this case study are speculative, due to lack of data from analysts observing the conflict, the development of a causal-loop diagram (CLD) helps identify possible reinforcing and balancing in the overall structure. Between the BOT diagram and CLD, analysts have a starting point for system behavior and dynamics (see Appendix B).

The BOT diagrams and CLD are only the beginning; decision analysts also need to collect data to simulate and verify the system's structure and make necessary modifications for further analysis. While qualitative and quantitative results facilitate timely decision making (with a CLD simulation), analysts still must constantly reassess the dynamic structure, look for repeating patterns of quick fixes (e.g., CT operations), determine how often these fixes occur, and compare their findings against the frequency with which the Malian government typically appraises its performance. Ultimately, sponsors, conveners, and analysts must remain vigilant against conceptual blocks that make us "prisoners of the system or prisoners of our own thinking."[40] The CLD suggests that if leaders fail to intervene appropriately and stabilize the Sahel expeditiously, a vicious cycle of unintended consequences will occur. This dilemma compounds if leaders fail to take timely action, because the opportunities and threats presented will likely change drastically over time. For a detailed explanation of the systems approach, see Appendix B.

C. STEP II-A. IDENTIFY: DESIGN APPROACH

This section identifies Step II-A in the decision-support process. Figure 4 illustrates the generative process of using systems and design thinking to eventually identify, prototype, and verify a solution.

[40] Senge, *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization*, 58–67; Peter M. Senge, "The Fifth Discipline," *Measuring Business Excellence* 1, no. 3 (1997), 46–51.

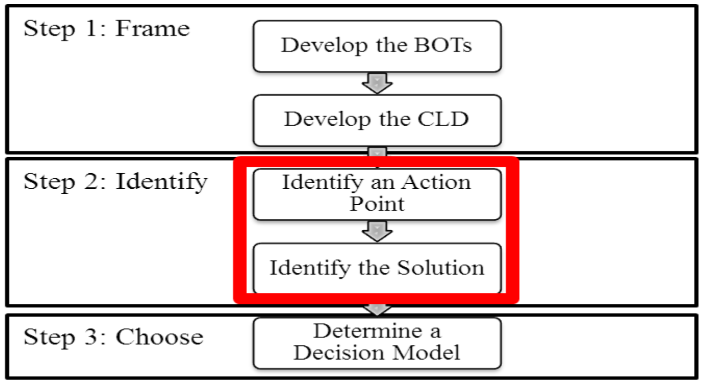

Figure 4. Step II—A Framework to Support Decision Makers

Key terms regarding the design approach are highlighted in Table 2.

Table 2. Coping with Wicked Problems: Design Approach.

Terms	Attributes	Definitions
Step II-A: Identify Design Approach	Change oriented	The design approach is a data-driven, collaborative, problem-solving process that invites people who live with the problem to frame it, establishes the parameters and constraints of the solution search, identifies creative ideas as solutions, rapidly prototypes and tests solutions in the field, collects feedback, and reframes problems and solutions wherever the data-driven process (not ideology) leads.[41] Buchanan summarizes it as "the systematic approach to the invention of possibilities."[42] Additionally, Brown and Wyatt suggest that design is a system of overlapping spaces, particularly the inspiration and ideation spaces.[43] Brown suggests that, at its core, design is a human-centered approach to problem solving, or what some have referred to as the "return of human beings to the center of the story."[44]
	Holistic	
	Integrative	
	Collaborative	
	Leader activated and orchestrated	
	Research reliant—not research constrained	
	Embodied	
	Action oriented	

[41] Roberts, "Tackling Wicked Problems in Indonesia," 2–3.

[42] Richard Buchanan, "Wicked Problems in Design Thinking," *Design Issues* 8, no. 2 (Spring, 1992, 1992), 5–21, http://www.jstor.org/stable/1511637, 13.

[43] Tim Brown and Jocelyn Wyatt, "Design Thinking for Social Innovation," *Development Outreach* 12, no. 1 (2010): 29–43.

[44] Tim Brown, *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation* (New York: Harper Collins, 2009), 39.

First, decision analysts should define key interrelated variables to segue into the major causal factors in the problem. Next, they should explore the application of interventions (e.g., the unintended consequences) in the wicked problem. Provided that the intervention represents long-term investments, analysts must explore whether the government can propose a new idea that will be widely accepted and serve as a cornerstone of sustainable development. Finally, decision analysts should prototype the new idea to dissuade opponents from dismissing the intervention.

From one perspective, the Malian government entered wicked-problem territory when violent NSAs began collaborating to destabilize Northern Mali. A perfect storm occurred when the NSAs pursued "coping strategies" by rebelling against the government to save their identity. For example, the Tuareg tribes traditionally lived a nomadic lifestyle and generally espouse a Berber/Muslim worldview. But due to lack of government support in rural desert areas, the Tuaregs are progressively living more sedentary lives. Recognizing the Tuaregs' feeling of disenfranchisement and marginalization, al-Qaida promulgated its brand and vision of Islam under the guise of honoring the Tuareg identity, and al-Qaida operatives have made a concerted effort to provide minor humanitarian aid and marry into the Tuareg tribes.[45]

Although the Malian government and its allies recognized that a problem existed, decision makers responded with quick-fix CT operations that ignored unintended consequences and exacerbated the original problem (e.g., French–Malian CT operations targeted VEOs; however, the government failed to provide basic and essential services to its citizens in the rural areas of Northern Mali). The government focused on terrorist symptoms—which had a tendency to subside for a short period and then reappear—instead of long-term, sustainable-development projects, including political, economic, social, and military interventions aimed at reducing violence, famine, and economic

[45] For example, Mokhtar Belmokhtar has become effective in the Sahel, because he has married four women from prominent Tuareg and Bérabiche families. His wives' families and clans have provided him with refuge and their protection, making it more difficult for him to be apprehended. Ricardo René Larémont, "Al Qaeda in the Islamic Maghreb: Terrorism and counterterrorism in the Sahel," African Security 4, no. 4 (2011), 242–268, 249.

Tim Brown and Jocelyn Wyatt, "Design Thinking for Social Innovation," *Development Outreach* 12, no. 1 (2010), 29–43.

disparities. Had long-term fixes geared toward sustainable development been implemented, decision makers could have broken the cycle of endlessly tackling unsolvable symptoms and the government could have begun taking comprehensive approaches to address a "systems of problems."[46] However, the government must be willing to invite all of the key stakeholders into a negotiations and consensus building session to even comprehend the complex systems of problem. Armed with information from negotiation with key stakeholders, design teams then devote maximal energy and time to explore the causal and systemic problems. In addition, conveners and decision makers can finally develop guidance, policies, and strategies that tackle the unintended-consequence variable efficaciously. Using the design approach, this thesis asserts that interventions of sustainable development have superior potential to materialize and solve root problems. For a detailed explanation of the design approach, see Appendix C.

[46] Russell L. Ackoff, *Redesigning the Future* (Hoboken, NJ: John Wiley, 1974).

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IV. PART II–THE DECISION SUPPORT PROCESS: QUALITATIVE REVIEW–B

Moving beyond a systems approach to framing the problem and a design approach to identifying an intervention, this chapter focuses on Step II-B of the decision-support process: evaluating a policy and strategy to identify limitations.

A. STEP II-B. IDENTIFY: EVALUATE U.S. POLICY AND STRATEGY

> The political object, as the original motive of the War, will be the standard for determining both the aim of the military force and also the amount of effort to be made.[47]

Once decision analysts define a problem using systems and design thinking, they should ensure that the intervention corresponds with U.S. policies and strategies, with all its nuances. Liddell Hart defined strategy as "…the art of distributing and applying military means to fulfill the ends of policy."[48] Analysts should view war with a "whole-of-government approach," i.e., via the prism of PMESII or political, military, economic, social, infrastructural, and informational dimensions.[49] As politicians and diplomats create policy, AFRICOM can develop strategies to inform policy, in a perpetual feedback loop. In the grand scheme, the president's national-security strategy serves as the point of departure for policy and strategy. This section explores how policy and strategy converge. Military strategies should be nested with policy—but are there any tangible or intelligible directives to which analysts can link their plans?

1. Policy Documents

At a minimum, analysts must review relevant U.S. policy and strategic documents, including the following:

1. National Security Strategy (NSS)

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[47] Carl Von Clausewitz, *On War* (New York: Digireads Publishing, 2004), 28.

[48] Basil Henry Liddell Hart, *Strategy: The Indirect Approach* (London, UK: Faber, 1967), 335.

[49] John Langton and Subrata Das, *A Framework for Building and Reasoning with Adaptive and Interoperable PMESII Models* (Cambridge, MA: Charles River Analytics, 2007). http://www.dtic.mil/cgi–bin/GetTRDoc?AD=ADA475419&embedded=true&Location=U2&doc=GetTRDoc.pdf.

2. Quadrennial Diplomacy & Development Review (QDDR)
3. DOS Bureau of African Affairs (S-AF)
4. DOS Bureau of Near Eastern Affairs (S-NEA)
5. U.S. Ambassador to Mali: Integrated Security Plan

Table 3 briefly annotates these documents.

Table 3. U.S. Policy: Analyzing Key Documents

Policy	Date	Purpose
NSS (Policy)	MAY 2010	The NSS is published by the executive branch of the U.S. government, and it is intended to be a comprehensive statement articulating the worldwide interests, goals, and objectives of the U.S. that are important to its security and deterring aggression.[50]
QDDR (Policy)	2010	The QDDR is a blueprint of using "civilian power" to advance national interests and to be a better partner to the U.S. military. Civilian power is directing and coordinating the resources of all America's civilian agencies to prevent and resolve conflicts; help countries lift themselves out of poverty into prosperous, stable, and democratic states; and build global coalitions.[51]
S-AF (Policy)	2014	The S-AF is focused on the development and management of U.S. policy concerning Africa, along the following four pillars: strengthening democratic institutions; supporting African economic growth and development; advancing peace and security; and promoting opportunity and development. [52]
S-NEA (Policy)	2014	The S-NEA tackles regional foreign policy issues: peace, terrorism, weapons of mass destruction, and political / economic reform.[53]

[50] President Barack Obama, *2010 U.S. National Security Strategy* (Washington, DC: The White House, 2010).

[51] U.S. Department of State, *2010 Quadrennial Diplomacy & Development Review* (Washington, DC: Department of State, 2010a).

[52] U.S. Department of State, "Bureau of African Affairs: Our Mission," Department of State, Bureau of Public Affairs, accessed 05 February, 2014, http://www.state.gov/p/af/188266.htm.

[53] U.S. Department of State, "Bureau of Near Eastern Affairs; Regional Policy," U.S. Department of State, accessed May 5, 2014, http://www.state.gov/p/nea/. The NEA's regional policy is a classified document; therefore, the author accessed the NEA's unclassified strategic vision on regional policy.

Policy	Date	Purpose
U.S. Ambassador to Mali Integrated Country Strategy	2014	The plan suggests that bilateral development aims to strengthen democracy, promote human rights, protect the environment and improve health care and education. The U.S. will reengage Malian security institutions and military assistance, while prioritizing security sector reform, professional norms, reassertion of civilian authority, accountability mechanisms, and the rule of law. With the international community and the new Malian government, the U.S. will support comprehensive solutions that promote development and security throughout Mali.[54]

2. Strategic documents:

The strategic documents needed for thorough analysis of the wicked problem include the following:

1. National Defense Strategy (NDS)
2. National Military Strategy (NMS)
3. Quadrennial Defense Review (QDR)
4. AFRICOM Posture Statement
5. JSOTF-TS Mission

Table 4 lists the purpose of each strategy document.

Table 4. U.S. Strategy: Analyzing Key Documents

Strategy	Date	Purpose
NDS	JAN 2012	The NDS sets priorities for defense to sustain global leadership, while reflecting the president's strategic direction. It is informed by its civilian and military leadership.[55]
NMS	FEB	The NMS is a vision for joint force employment of capabilities

[54] Leonard, Mary Beth, "U.S. Ambassador to the Republic of Mali: Embassy's Bilateral Assistance Programs," accessed September 6, 2014, http://mali.usembassy.gov/statement_09062013.html. The ambassador's integrated country strategy is classified; therefore, the author accessed the U.S. ambassador's website to acquire a high level vision on bilateral assistance. The integrated security strategy (ICS) is the consideration of U.S. national security through the interrelationship among the security of the existence of Mali. In particular the ICS consists of a plan to deal with the following types of security for Mali: economic, internal, human, environment, information and so forth.

[55] U.S. Department of Defense, *2012 Defense Strategic Guidance: Sustaining U.S. Global Leadership, Priorities for 21st Century Defense* (Arlington, VA: Department of Defense, 2012).

Strategy	Date	Purpose
	2011	to protect and defend the nation and its allies.[56]
QDR	MAR 2014	The QDR is a legislatively-mandated review of DOD long-term strategy and priorities. It assesses challenges and re-balances strategies, capabilities, and forces to address future threats.[57]
AFRICOM Posture	MAR 2014	This statement reveals AFRICOM's posture to address increasing U.S. interests, transnational threats, and crises.[58]
JSOTF-TS	2014	JSOTF-TS Supports partner nations and conducts special operations as directed, in coordination with U.S. Embassy country teams.[59]

3. Strategy and Strategy: A More Indirect Approach

> In strategy the longest way round is often the shortest way there; a direct approach to the object exhausts the attacker and hardens the resistance by compression, whereas an indirect approach loosens the defender's hold by upsetting his balance.[60]

The cascading effects of U.S. interests and objectives flow from policy to military strategy. However, according to current policy and strategic documents, the VEOs and violent NSAs in Northern Mali do not pose an immediate threat to U.S. interests. It appears that decision makers are concerned only with VEOs that are affiliated with the al-Qaida franchise. In fact, strategic assessments appear to evaluate VEOs and violent NSAs as merely leveraging the al-Qaida brand to promote their limited, regional causes and not the greater global jihad that al-Qaida wages as the vanguard VEO. However, the NSS and

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[56] U.S. Department of Defense, *2011 National Military Strategy* (Arlington, VA: Department of Defense, 2011).

[57] U.S. Department of Defense, "2014 Quadrennial Defense Review," Department of Defense, accessed April 01, 2014, http://www.defense.gov/home/features/2014/0314_sdr/qdr.aspx.

[58] In addition to the posture statement, the analyst would need to analyze the TCP 7000–12 (or Theater Campaign Plan with its associated Base Plan and Annexes). *2014 U.S. Africa Command Posture Statement: Statement of General David Rodriguez before Senate Armed Services Committee* 113th Cong (2014) (testimony of David Rodriguez).

[59] Joint Special Operations Task Force—Trans Sahara, "JSOTF–TS Mission," Joint Special Operations Task Force—Trans Sahara, accessed May 05, 2014 http://www.socafrica.africom.mil/component/JSOTF–TS.asp.

[60] Liddell Hart, *Strategy: The Indirect Approach.*

QDDR are not up-to-date policy documents reflecting the realities of the conflicts in Northern Mali, or North Africa, for that matter. Therefore, the AFRICOM commander must continue to ensure that his subordinate commanders are constantly adapting their regional strategies per the S-AF, the S-NEA, and various U.S. embassies across the continent.[61] Otherwise, VEOs and violent NSAs will continue to exploit DOD–DOS communication gaps.

Still, VEOs and violent NSAs have the potential to become greater threats to U.S. interests. The 2012 coup d'état in Mali proved that VEOs and violent NSAs could destabilize Northern Mali. As VEOs conduct kidnap-for-ransom operations to fund terrorist activities, smuggle drugs to finance operations in Europe, conduct arms trafficking, impose Sharia law, and promulgate other nefarious activities, U.S. policymakers must update their directives so that military decision makers can adjust strategy accordingly. Otherwise, the military will continue to pursue the direct approach by conducting or supporting CT operations and reactively chasing obsolete fixes that fail (see appendices A, B, and H).

While falling in line with other combatant-command efforts in post-9/11 conflicts, AFRICOM has also pursued General John Abizaid's notion of the "long war" strategy.[62] For example, AFRICOM sought to achieve policy directives through the annual Flintlock exercises in the trans-Sahara. Flintlock involved regional state-actor militaries in conducting CT-related exercises to maintain African partnerships and security apparatuses, in an effort to deal with VEOs and violent NSAs. AFRICOM executed other CT programs through the Trans-Sahara Counterterrorism Partnership (TSCTP) as well. Yet despite the short-term successes of the direct approach, the problem set remains wicked. From 2012 to 2014, the U.S. has nevertheless been supporting French–Malian CT operations in Northern Mali (see Appendix L).

[61] DoDD 5205.75 states that DOD personnel in a foreign country who are not under the command of a U.S. geographic combatant commander (GCC) will be under the authority of the chief of mission (COM) in that country. U.S. Department of Defense, *Department of Defense Directive 5205.75: DOD Operations at U.S. Embassies* (Arlington, VA: Department of Defense, 2013), 2.

[62] Bradley Graham and Josh White, "Abizaid Credited with Popularizing the Term 'Long War,'" *Washington Post* 3 (2006), A08.

Under the circumstances, strategists and decision analysts should contemplate what policy has to say about the indirect approach. U.S. decision makers agree on structural aspects of improving African-partner capacity, security apparatuses, and governance; however, military decision makers should adapt their current strategy to complement civilian power, other soft-power initiatives, and indirect approaches across the DIMEFIL domains.[63] More pointedly, AFRICOM should alter its strategy to better accommodate the sustainable-development strategy promoted by the S-AF and S-NEA. Military strategies supporting an indirect approach would likely dissuade the DOS from spoiling AFRICOM efforts in Northern Mali, the trans-Sahara, and the rest of Africa. AFRICOM must do all it can to promote consensus building among ambassadors, DOS decision makers, and other civilian leaders in a way that proves that conflicts will not metastasize. The criticisms of the DOS by the Association of Concerned African Scholars (ACAS), for example, who claimed that the TSCTP was militarizing U.S. policies,[64] might thus have been avoided.

The ACAS's anxiety likely stemmed from AFRICOM's failure to incorporate a supporting strategy for soft-power initiatives and activities wielded by the U.S. Agency for International Development (USAID) and other diplomatic agencies. Bearing this in mind, AFRICOM must devise mission directives that convincingly de-escalate problems and remain unassuming. Operations and activities conducted by the USAID, non-government organizations (NGOs), various international organizations, private organizations, and so forth rely on a do-no-harm image of neutrality and objectivity. In that vein of sustainable development, AFRICOM must adapt to the DOS's fundamental school of thought to succeed in promoting American interests in Northern Mali.

[63] Analysts should view the indirect approach in the way that Szafranski argues that military power resides in the domain of the mind and the will; the provinces of choice, "thinking," valuing or "attitude," and insight or "imagination." The indirect approach should resemble what Szafranski refers to as neocortical warfare, which "…strives to control or shape the behavior of enemy organisms, but without destroying the organisms. It does this by influencing, even to the point of regulating, the consciousness, perceptions and will of the adversary's leadership: the enemy's neocortical system." Richard Szafranski, "Neo-Cortical Warfare? The Acme of Skill," *Military Review* (1994), 41–55.

[64] Arieff, *Crisis in Mali*, 15–16.

By considering how to complement the DOS's approach to sustainable development, AFRICOM can truly fulfill the president's NSS, which seeks a whole-of-government approach.[65] More importantly, the strategy will be more congruent with the ever-changing operational environment. Just as the 1986 Goldwater–Nichols Act calls on the interagency to collaborate,[66] military strategies must relate to policy. Beyond the benefits of eliminating redundancies and wasted efforts, the interagency can work more cohesively toward defeating VEOs in Northern Mali.

With a more synergistic military strategy, AFRICOM can influence wicked problems by intervening in the causal factors of terrorism. Until the president and DOS alter policy in the Malian region, however, AFRICOM would do well to follow the four key themes of the QDDR:[67]

1. Build U.S. civilian power, bringing together the unique contributions of civilians across the federal government to advance U.S. interests.
2. Elevate and transform development to deliver results by focusing our investments, supporting innovation, and measuring results.
3. Build a civilian capacity to prevent and respond to crisis and conflict and give our military the partner it needs and deserves.
4. Change the way we do business by working smarter to save money, planning and budgeting to accomplish our priorities, and measuring the results of our investments.

Additionally, all six of AFRICOM's functionally aligned directorates must synchronize their strategies and nest them with the DOS, as depicted in Figure 5.

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65 U.S. Department of Defense, *2011 National Military Strategy*, 6.

66 Goldwater–Nichols Department of Defense Reorganization Act of 1986. Pub. L. No. 99–433 (1986). President Ronald Reagan signed the Goldwater–Nichols Act, which attempted to make sweeping changes throughout the DOD to solve problems caused by inter-service rivalry. Following the failures of the Vietnam War, and 1980 Iranian hostage rescue, the Congress passed the new bill.

67 U.S. Department of State, *Quadrennial Diplomacy & Development Review: A Summary* (Washington, DC: U.S. Department of State, 2010).

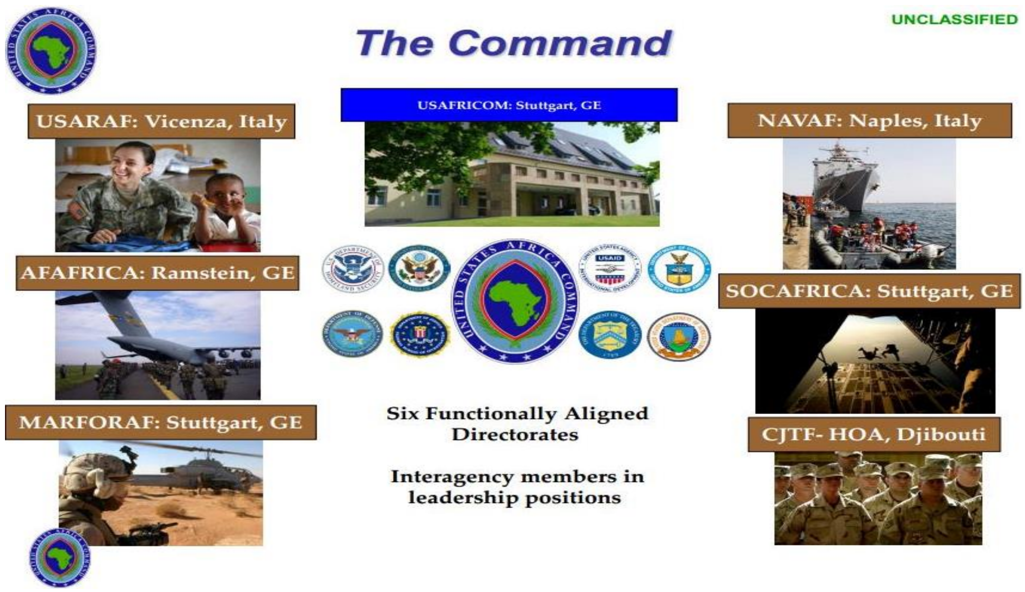

Figure 5. The Six Functionally Aligned Directorates of AFRICOM[68]

B. THE DANGERS OF NOT COORDINATING STRATEGY AND POLICY

By focusing on DIMEFIL's soft powers (in the diplomatic, information, and economic domains), the interagency community can collectively leverage its unique contributions to advance U.S. interests. To succeed in this indirect approach, AFRICOM must reprioritize its missions to support development, refocus investments, promote innovation, and measure results. A military strategy that supports the notion of building civilian power and capacity to prevent or respond to crises allows the DOS to collaborate with AFRICOM. By changing the way AFRICOM does business, the interagency and the elements of national power will deal more intensely with the following factors:

1. Fiscal limitations and realities
2. Planning, programming, budgeting, and execution to achieve U.S. priorities
3. Evaluating the results of its investments

Figures 6 and 7 illustrate DOS, USAID, and DOD relationships and funding in Africa.[69]

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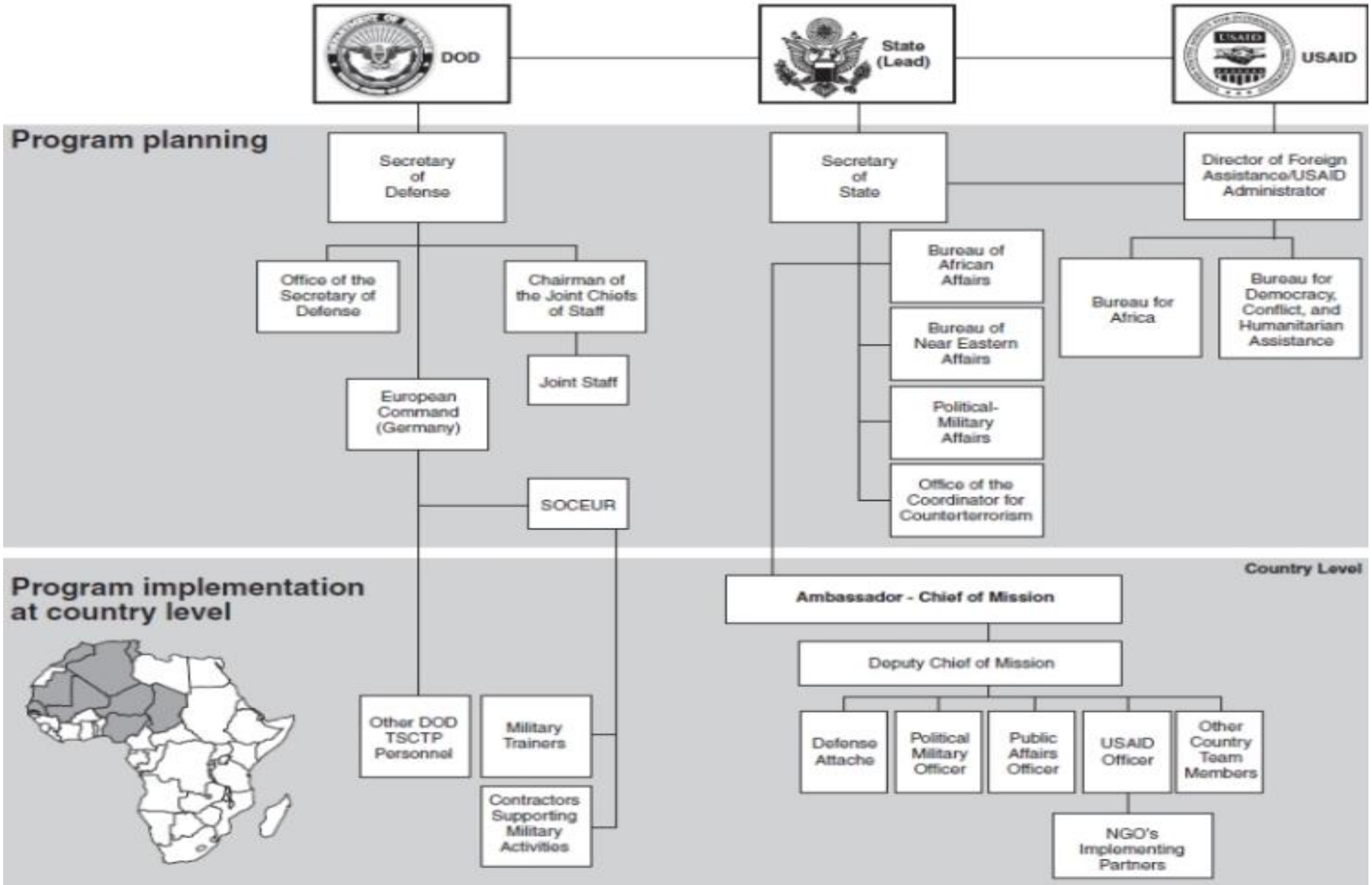
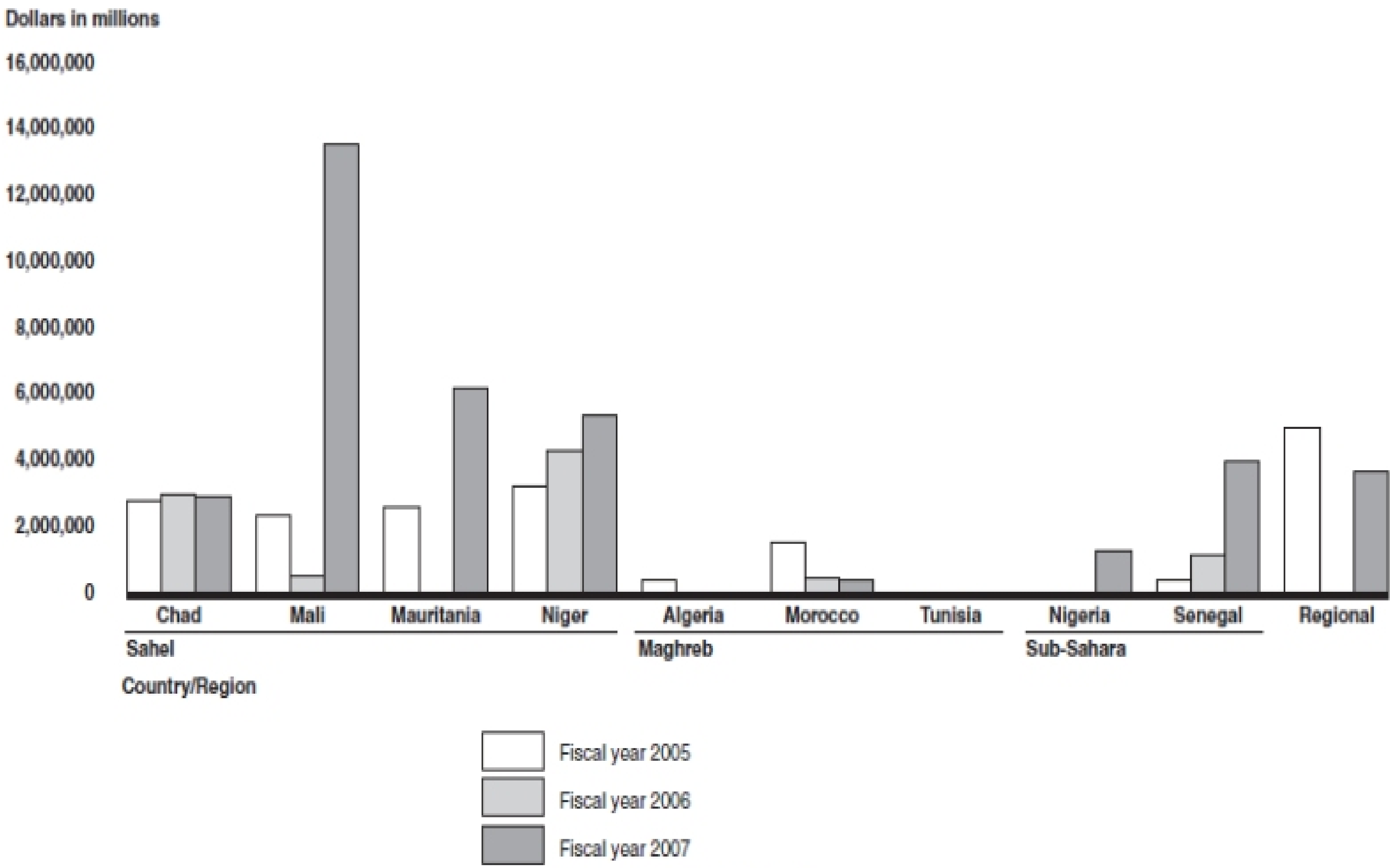
[68] U.S. Africa Command, *USAFRICOM Directorate for Logistics—J4: Engineer Division—J44.*

[69] U.S. Government Accountability Office, *GAO Analysis of State, USAID, DOD Data.*



Sources: GAO analysis of State, USAID, and DOD data; Art Explosion (images).

Figure 6. DOS, DOD, and USAID Relationships



Source: GAO analysis of State and USAID data.

Figure 7. DOS and USAID Funding for TSCTP

The wicked problems in Northern Mali will likely persist so long as DOD and DOS decision makers do not collaborate more effectively (see Appendices A, B, and C for a detailed explanation). Wicked problems derive "…from the interdependencies and complexities of living together without a shared set of values and views."[70] Ultimately, the literature suggests that AFRICOM should work with its partners to develop effective coping strategies that are collaborative in nature. The more U.S. decision makers collaborate, the better they can work toward sustainable development in Northern Mali, even while tackling crises.

[70] Roberts, *Wicked Problems and Network Approaches to Resolution*, 1–19, 16.

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V. PART III–THE DECISION-SUPPORT PROCESS: A QUANTITATIVE REVIEW

This chapter presents Step III in the decision-support process: integer programming (IP) to model the problem.

A. STEP III–CHOOSE: INTEGER PROGRAMMING

Real-world scenarios are not always linear; however, decision analysts can help simplify wicked problems with decision models such as the binary-integer-programming (BIP) approach proposed in this thesis. Proper BIP modeling can help analysts make resource-allocation decisions so as to target VEOs and violent NSAs. To effectively allocate resources, this research investigates one way that analysts formulate, solve, and interpret a problem. The formulation step involves the process of expressing and translating each aspect of the wicked problem in terms of simple mathematical expressions.[71] Throughout formulation, the analyst ensures that the mathematical equations employed address issues relevant to Northern Mali. Regarding the development of a solution, analysts must ensure that these mathematical expressions determine values for variables and identify an optimal solution. With proper formulation and the selection of an optimal solution, the analyst can interpret the BIP model and assess the impact of the decision.

Decision analysts often encounter problems in which there are two or more objective functions that need to be optimized simultaneously. This research, however, uses BIP models to develop only one set of optimization objectives. In this case, the analyst optimally allocates sustainable-development projects to 24 communes while maximizing the total amount of rehabilitation. Ultimately, leaders have simple binary-integer solutions, denoted by "yes" or "no" (1 or 0, respectively) to help with the decision-making process. This section outlines the framework for developing the BIP model by briefly presenting popular LP problems: set covering, transportation, and assignment.

[71] Balakrishnan, Render, and Stair, *Managerial Decision Modeling with Spreadsheets*, 21.

B. THE SET-COVERING PROBLEM

The key principle of LP is that interactions exist among variables. In the case of Northern Mali, adjacency constraints limit the degree to which the government can build sustainable-development projects. The BIP model leverages these adjacency constraints, which forces the projects to support more than one commune at a time. In other words, the constraints allow a decision analyst to limit the redundancy of sustainable-development projects by identifying optimal project sites that serve multiple neighboring communes. Analysts commonly refer to this application of BIP modeling as "set covering." In this particular study, set covering allows the analyst to optimally cover key areas throughout Northern Mali.[72]

The decision analyst designs the set-covering constraint under the assumption that a single project can serve or influence neighboring or adjacent communes. By ensuring that at least one project covers multiple communes, the analyst gives decision makers a starting point from which to begin negotiations. If necessary, the analyst can add a constraint that avoids incompatible selections or mutually exclusive choices;[73] for example, the analyst could add the constraint of disallowing more than one project to serve a commune. Similarly, the decision maker could dictate that an exact quantity of projects covers each commune. Ultimately, the set-covering constraint allows a project to cover multiple communes.

C. THE TRANSPORTATION PROBLEM

Models involving transportation problems involve the distribution of goods and services from multiple supply points (also called origins or sources) to multiple demand points (also called destinations or sinks), at some cost.[74] This application maximizes the profits or minimizes the cost of shipping goods between locations while meeting the needs and capacity of each arrival point. Although decision analysts can solve transportation problems with algorithms more economical than the simplex method, this

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[72] Ibid., 220.

[73] Ibid., 222.

[74] Ibid., 162.

thesis tames the complexity of the problem set by reducing thousands of variables and constraints to a few hundred. As analysts contemplate whether the problem they are tackling is similar to a transportation problem, they should recall a special type of transportation problem: the "assignment problem."

D. THE ASSIGNMENT PROBLEM

The assignment problem is a subclass of the transportation problem, in which the supply-and-demand variables are integral. Assignment models can involve choosing optimal, one-to-one assignments of soldiers to bases, military units to territories, contracts to bidders, and so forth.[75] As decision analysts seek to find an optimal assignment of soldiers or units to unique mission sets—without assigning a soldier or unit to more than one mission—they must ensure that all missions are completed. Ultimately, the analyst chooses to minimize or maximize some objective. Unlike the transportation problem, the assignment problem has more wide-ranging uses in applying combinatorial optimization to the real world. In this study, analysts can use it to assign sustainable-development projects to particular regions.

1. Assignment Example: Palmer and Innes (1980)

Palmer and Innes offer many examples in operational research, and in particular, the authors present several simple assignment problems that support the model-development process in this thesis.[76] An example is a problem where analysts learn the difference between the assignment technique and the transportation method described in the previous sections by considering a firm trying to determine where to build or allocate five warehouses, with six possible sites available. The driving factor is the cost of building the warehouses at the different locations, so the firm must learn the total minimum cost of building five warehouses and where to build them. In another instance, five doctors who just started a private practice want to provide services to five areas. The

[75] Ibid.

[76] Colin F. Palmer and Alexander E. Innes, *Operational Research by Example* (London, UK: Macmillan, 1980).

goal in the problem is to minimize the distance they have to travel to each area. The questions and principals behind these simple examples are foundational to the approach used in this research.

2. Assignment Example: Koopmans and Beckmann (1957)

Quadratic-assignment problems (QAPs) are among the most complex combinatorial optimization problems. Scores of academics, authors, and other professionals have expanded on QAP methodology, because of its richness in solving real-world applications. Padberg and Manfred build on Koopmans and Beckmann's work on QAP,[77] producing what they refer to as the KBP. KBP methodology explores the problem of assigning indivisible economic activities to locations. KBP or QAP methodology allows the modeler to assign *n* plants to *n* locations, while ensuring that the interaction cost is proportional to the flow between the plants, multiplied by the distances between the locations. The modeler must also account for the costs of placing the plants at their locations. Ultimately, the QAP's objective is to allocate each plant to some location while minimizing total cost. Padberg and Manfred elaborate on the KBP model by applying the location/assignment problem in the U.S and comparing three modifications of the KBP: the changed, modified, and symmetric versions.

[77] Manfred Padberg and Minendra P. Rijal, *Location, Scheduling, Design and Integer Programming*, Vol. 19 (Boston, MA: Kluwer Academic, 1996), 14–20; Tjalling C. Koopmans and Martin Beckmann, "Assignment Problems and the Location of Economic Activities," *Econometrica: Journal of the Econometric Society* (1957): 53–76, 64–71.

VI. PART IV–THE DECISION-SUPPORT PROCESS: IP MODELING

This chapter focuses on Step IV-A (formulate) of the decision-support process to determine solutions to regain control of Northern Mali: define the problem, develop a model, and acquire the data.

A. MODEL, MATERIALS, AND METHOD

Model I–Set Covering and Model II–Realm of Influence are covered in the following sections:

1. Model Description
2. Model Development
3. Materials
4. Methodology

Figure 8 illustrates the Step IV-A of the decision-support process.

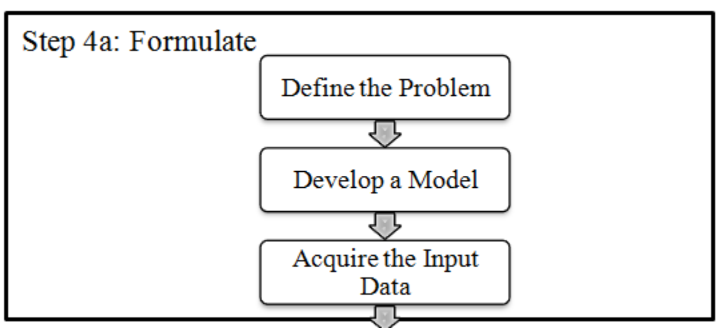

Figure 8. Step IV-A: Formulate

B. MODEL I–SET COVERING: MODEL DESCRIPTION

This section describes the use of deterministic, mathematical programming to optimally assign a limited number of sustainable-development projects, by type, across Northern Mali. By "optimally" is meant the best possible allocation of projects, all other things being equal, to achieve maximal rehabilitation throughout the region. In other words, the model weighs varying levels of desert degradation while allocating projects to achieve the greatest rehabilitation possible. It must be noted that, due to limited resources, the supply of projects will not meet the demands of key stakeholders and decision makers.

Since decision analysts will not be able to assign every commune an ideal project, they must assign projects optimally, based on rehabilitation scores. First, analysts determine each commune's quality score by developing a mathematical function to account for eight quality factors and measuring the degree of sustainable development needed. Then the analyst determines the value of sustainable development projects. In this scenario, there are four types of projects (or four project designs) of which the model assigns to communes. The rehabilitation scores depend upon how the model matches projects to communes. The model uses the equation below to determine rehabilitation scores (see Equation 3).

$$Q_{ij} = (P_j - C_i) \in \mathbb{R}$$
$$\text{and} \quad i = \{1, \ldots, 47\},\ j = \{1, 2, 3, 4\}$$
$$\text{(sets and indices are defined below)}$$

The objective function, subject to multiple constraints, allows the analyst to compare the rehabilitation scores and match projects and communes optimally to achieve a total maximum rehabilitation, as shown below (see Equation 5).

$$Max = \sum_{j=1}^{4} \sum_{i=1}^{47} Q_{ij} x_{ij}$$
$$\left(\text{sets, indices, and variables are defined below}\right)$$

Developing a model in this fashion gives the analyst a starting point from which decision makers can begin negotiations, consensus building, model refinement, and collection of more accurate, classified data.

1. Objective of the Model

The objective of the decision model is to offer decision makers a starting place for developing options to combat or reverse desertification in Northern Mali. By optimally distributing a limited number of sustainable-development projects across the region, decision makers can hope to develop fair options that are agreeable to the majority of key stakeholders. Therefore, the objective function is subject to decision-maker preferences (demand constraints), “brute” constraints to address high-threat communes (demand constraints), constraints based on the availability of projects (supply constraints), set-covering constraints to cover neighboring communes, and binary constraints. To clearly inform decision makers, the model’s decision variables are in the form of binary variables that indicate the assignment of a project to a commune. Analysts should apply the objective of the model to the following problem statement:

The DOD, DOS, interagency organizations, coalitional partners, and other international organizations (hereafter referred to as the CJTF, or combined joint task force) have decided to intervene in the Sahel problem set with sustainable development. Specifically, decision makers have determined that the CJTF should intervene by implementing sustainable development to deter, displace, or defeat VEOs and violent NSAs. The goal is to regain control of Northern Mali. To optimally implement sustainable development, decision analysts must achieve the maximum rehabilitation possible, subject to numerous constraints. First, sustainable-development projects must influence key towns and cities assessed as a high-threat commune. Second, as the model determines where to allocate projects, it should also consider how projects are connected to each other, to gain optimal coverage in the region. For example, a single project may serve multiple communes.

In addition to rehabilitating desertified lands, the optimal allocation of projects will assist the government in regaining a proportion of control over the political space and some level of government compliance from the indigenous population. The analyst must determine which of the 47 communes should receive the sustainable-development projects. However, the analyst has a limited inventory of 24 projects. Furthermore, the analyst categorizes the projects into the following four project types:

1. Project Design 1 has a supply of six projects, with a quality score of 7.
2. Project Design 2 has a supply of eight projects, with a quality score of 8
3. Project Design 3 has a supply of seven projects, with a quality score of 9
4. Project Design 4 has a supply of three projects, with a quality score of 10

The open-source media reporting (see Chapter VI, Section D) suggest that the following eight communes are “high threat” (or VEO-controlled areas with violence or threat to human life) and must therefore receive a project: Aguelhok, Ansongo, Gao, Kidal, Menaka, Tessalit, Tombouctou, and Tinzouaten. Finally, decision makers hypothetically dictate that analysts strategically situate projects to target VEOs and violent NSAs directly or indirectly, or both. See Figure 9 for the layout of 47 communes in Northern Mali.

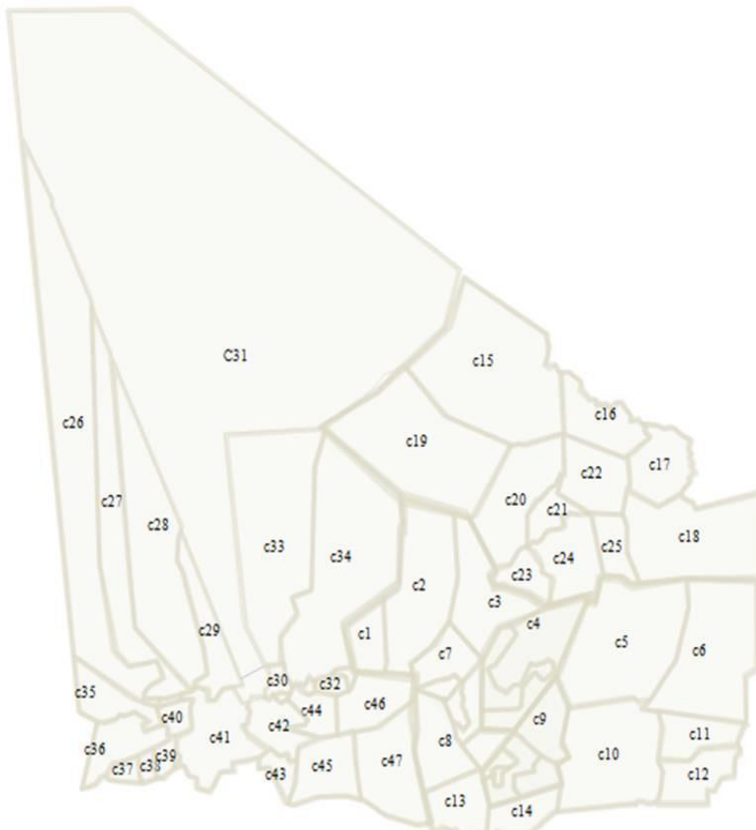

Figure 9. Northern Mali: Communes i, in the Gao, Kidal, and Tombouctou Regions

2. Model Development

a. Parameters of Model I

There are five main sets:

$C =$ set of all communes;

$P =$ set of all project designs;

$Q =$ set of commune quality scores;

$S_{i'i}$ = set of all communes i that surround commune i'; and

HTC = set of all high threat communes.

b. Indices

Model I assigns the following indices to communes, projects, and quality scores:

$i, i'-$ communes;
$j-$ project designs; and
$q-$ commune quality scores.

Let C_i be the sum of the set of quality scores for each commune *i* (see Appendix D, Section I); where

$$\alpha_{qi} = \text{ quality score } q \text{ for commune } i$$
$$C_i = \sum_{\forall q} \alpha_{qi}, \forall i \tag{1}$$

Let P_j be the quality score for each project *j*; where

$$\mathrm{P}_j \in \{7,8,9,10\} \quad \text{and} \quad j = \{1,2,3,4\}$$
$$\begin{aligned} P_1 &= 7 \\ P_2 &= 8 \\ P_3 &= 9 \\ P_4 &= 10 \end{aligned} \tag{2}$$

For projects denoted as P_1, 6 projects are available.

For projects denoted as P_2, 8 projects are available.

For projects denoted as P_3, seven projects are available.

For projects denoted as P_4, three projects are available.

In all, there are a total of 24 projects available.

Let Q_{ij} be the rehabilitation score, which is the difference between the quality scores for project *j* and commune *i*.

$$Q_{ij} = (P_j - C_i) \in \mathbb{R}$$
$$\text{and} \quad i = \{1, \ldots, 47\},\ j = \{1,2,3,4\} \tag{3}$$

Table 5 illustrates the rehabilitation scores for each project–commune combination. Therefore, the model uses the following 188 pre-defined sets (coefficients).

Table 5. Rehabilitation Scores Q_{ij}

Q_{ij}	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9	i=10
j=1	0.25	0.25	1.50	3.00	-0.50	0.25	2.25	0.25	2.00	2.75
j=2	1.25	1.25	2.50	4.00	0.50	1.25	3.25	1.25	3.00	3.75
j=3	2.25	2.25	3.50	5.00	1.50	2.25	4.25	2.25	4.00	4.75
j=4	3.25	3.25	4.50	6.00	2.50	3.25	5.25	3.25	5.00	5.75

Qij	i=11	i=12	i=13	i=14	i=15	i=16	i=17	i=18	i=19	i=20
j=1	3.25	2.25	0.50	0.50	3.25	1.25	1.25	1.25	0.25	2.50
j=2	4.25	3.25	1.50	1.50	4.25	2.25	2.25	2.25	1.25	3.50
j=3	5.25	4.25	2.50	2.50	5.25	3.25	3.25	3.25	2.25	4.50
j=4	6.25	5.25	3.50	3.50	6.25	4.25	4.25	4.25	3.25	5.50

Qij	i=21	i=22	i=23	i=24	i=25	i=26	i=27	i=28	i=29	i=30
j=1	1.25	1.25	0.25	2.50	1.25	0.25	0.25	0.25	2.00	2.25
j=2	2.25	2.25	1.25	3.50	2.25	1.25	1.25	1.25	3.00	3.25
j=3	3.25	3.25	2.25	4.50	3.25	2.25	2.25	2.25	4.00	4.25
j=4	4.25	4.25	3.25	5.50	4.25	3.25	3.25	3.25	5.00	5.25

Qij	i=31	i=32	i=33	i=34	i=35	i=36	i=37	i=38	i=39	i=40
j=1	1.25	2.00	0.25	1.00	1.25	1.00	2.75	1.50	1.50	1.00
j=2	2.25	3.00	1.25	2.00	2.25	2.00	3.75	2.50	2.50	2.00
j=3	3.25	4.00	2.25	3.00	3.25	3.00	4.75	3.50	3.50	3.00
j=4	4.25	5.00	3.25	4.00	4.25	4.00	5.75	4.50	4.50	4.00

Qij	i=41	i=42	i=43	i=44	i=45	i=46	i=47
j=1	4.75	1.00	2.00	1.00	1.00	2.00	0.00
j=2	5.75	2.00	3.00	2.00	2.00	3.00	1.00
j=3	6.75	3.00	4.00	3.00	3.00	4.00	2.00
j=4	7.75	4.00	5.00	4.00	4.00	5.00	3.00

Equation 3 allows the analyst to calculate the rehabilitation scores Q_{ij}, which are found in Table 5. When AFRICOM assigns a project *j* to commune *i*, the commune rehabilitates up to the quality score of project *j*. For example, in the top-left corner of the table, the analyst makes the following calculation (see Appendix F, Section I):

$$Q_{11} = (P_1 - C_1) \in \mathbb{R} \;\therefore\; Q_{11} = (7.00 - 6.75) = 0.25$$

c. *Decision Variables*

The optimization model uses x_{ij} for its decision variables.

Let x_{ij} be the binary decision variable,

$$\text{where } x_{ij} = \begin{cases} 1 & \text{if project } p_j \text{ is assigned to commune } i \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

$$\text{and } \quad i = \{1, \ldots, 47\},\; j = \{1, 2, 3, 4\}$$

d. Objective Function

The objective function maximizes the total value of rehabilitation.

$$Max = \sum_{j=1}^{4} \sum_{i=1}^{47} Q_{ij} x_{ij} \tag{5}$$

e. Constraints

Equation 6 is a set-covering constraint ensuring that each commune *i* is served by at least one project *j*.

$$\sum_{\forall i \in Si'i} x_{ij} \geq 1, \forall i \tag{6}$$

For example, when the set-covering constraint is applied to commune 1, it reads as follows (see Appendix F for all 47 set covering constraints):

$$\text{Covering, } \textit{commune} \text{ 1 is served by a project(s)}$$
$$(x_{1j} + x_{2j} + x_{32j} + x_{34j} + x_{46j}) \geq 1$$

Equations 7 to 10 are supply constraints, ensuring that every project *j* is assigned to at most one commune *i*.

$$\sum_{\forall i} x_{i1} = 6 \tag{7}$$
$$\sum_{\forall i} x_{i2} = 8 \tag{8}$$
$$\sum_{\forall i} x_{i3} = 7 \tag{9}$$
$$\sum_{\forall i} x_{i4} = 3 \tag{10}$$

For example, when the supply constraint is applied to project design 1, it reads as follows (see Appendix F for the details of all four supply constraints):

$$\text{Supply of project } j = 1, \text{ of which 6 are available}$$
$$\begin{pmatrix} x_{11} + x_{21} + x_{31} + x_{41} + x_{51} + x_{61} + x_{71} + x_{81} + x_{91} + x_{101} + x_{111} + x_{121} + x_{131} + \\ x_{141} + x_{151} + x_{161} + x_{171} + x_{181} + x_{191} + x_{201} + x_{211} + x_{221} + x_{231} + x_{241} + x_{251} + \\ x_{261} + x_{271} + x_{281} + x_{291} + x_{301} + x_{311} + x_{321} + x_{331} + x_{341} + x_{351} + x_{361} + x_{371} + \\ x_{381} + x_{391} + x_{401} + x_{411} + x_{421} + x_{431} + x_{441} + x_{451} + x_{461} + x_{471} \end{pmatrix} = 6$$

Equation 11 is the demand constraint ensuring that every commune *i* receives at most one project *j*.

$$\sum_{\forall j} x_{ij}, \forall i \tag{11}$$

For example, when the demand constraint is applied to commune 1, it reads as follows (see Appendix F for the details of all 47 demand constraints):

$$\text{Demand from } commune \text{ 1 for project } j \quad (x_{11} + x_{12} + x_{13} + x_{14}) \leq 1$$

Equation 12 is a simple demand constraint that assigns at least one project *j* to each of the following high-threat communes (HTC): 7, 9, 10, 15, 17, 20, 24, and 32.

$$\sum_{\forall j} x_{ij} \geq 1, \forall i \in HTC \tag{12}$$

For example, when the brute constraint (or HTC) is applied to Commune 7, it reads as follows (see Appendix F for the details of all eight HTC constraints):

$$\sum_{j=1}^{4} x_{7j} \geq 1$$

Equation 13 is a binary constraint, which forces the analyst to select or reject (1 or 0) the assignment of a project *j* to a commune *i*.

$$x_{ij} = 1 \text{ or } 0, \forall ij \tag{13}$$

3. Limitations

The first limitation deals with the objective function maximizing the allocation of projects to the various communes, based on rehabilitation scores. In this scenario, the decision analyst can assign only one project to each commune to achieve the best possible rehabilitation score, Q_{ij}. Also the model's 108 constraints limit the model, because they allow for mutually exclusive alternatives and contingent decisions. Another limitation is the model's representation of a yes-or-no decision model, rather than a decision that determines how much.

C. MODEL II–REALM OF INFLUENCE: MODEL DESCRIPTION

Like Model I, this section describes the use of deterministic, mathematical programming (i.e., BIP modeling) to optimally assign a limited amount of sustainable-development projects, by type, across Northern Mali. However, Model II calculates commune quality scores, c'_i, differently. While optimally allocating projects to achieve the greatest rehabilitation, the model weights a commune's quality score.

Due to the lack of adherence to external and internal borders in Northern Mali, analysts may develop a second model with quality scores c'_i that are distributed by some proportionality to bordering communes. In other words, the model seeks to determine the realm of influence each commune has vis-à-vis another. The analyst accomplishes this concept by modifying Equation 1 from Model I. The new equation to determine c'_i (i.e., Equation 14) weights the sustainable-development factors α'_{qi} in the following fashion:[78]

1. It sums quality factors α'_{qi} and weights them such that each commune receives 50 percent of its total sum.
2. Then it distributes the remaining 50 percent of the score for c'_i to the communes that surround or share a border with c'_i.
3. In effect, this indicates that a commune's quality score will contribute to the quality scores of surrounding communes and vice versa.

Still, decision analysts will not be able to assign every commune an ideal project. However, Equation 114 accounts for the relationships shared by neighboring communes across the eight sustainable development factors, α'_{qi}. In other words, the new equation for c'_i tries to account for NSAs not recognizing the internal borders that France established in the early twentieth century.

Still, Model II optimally assigns projects based on rehabilitation scores Q'_{ij}. Analysts determine each commune's quality score, c'_i, by developing a mathematical function to account for the eight weighted quality factors of a commune α'_{qi} to measure

[78] Analysts should adjust Equation 14 immediately following site surveys, due to possible concerns regarding independence of observations.

the degree of sustainable development needed (see Equation 14) Depending on the allocation of projects P'_j, the analysts can determine rehabilitation scores Q'_{ij}. The objective function, subject to multiple constraints, allows the analyst to optimally allocate projects to achieve a total maximum amount of rehabilitation.

1. Objective of the Model

Analysts optimally allocate projects while accounting for the eight weighted α'_{ij} factors to derive the communes' scores c'_i. Otherwise, the objective function presented in Model I matches Model II (Equation 18). Except for the covering constraints described in Model I, Equation 18 is still subject to the same constraints. The decision variables for Model II are still in the form of binary variables to indicate the assignment of a project *j* to a commune *i*. The problem statement and goal remain the same as Model I (that is, regain control of Northern Mali).

2. Model Development

a. Parameters of Model I

There are six main sets:

$C' =$ set of all communes;
$n =$ set of all communes that surround C'
$P' =$ set of all project designs;
$Q' =$ set of commune quality scores;
$Si'i$ = set of all communes i that surround commune i'; and
HTC' = set of all high threat communes.

b. Indices

Model I assigns the following indices to communes, projects, and quality scores:

i, i' – communes;
k – communes i that surround commune i';
j – project designs; and
q – commune quality scores.

Let C'_i be the sum of the set of quality scores for each commune *i*, where

$$\alpha'_{qi} = \text{ quality score } q \text{ for commune } i$$
$$C'_i = \sum_{\forall q}\left(\frac{1}{2}\right)\alpha'_{qi}, \forall i + \sum_{k=1}^{K}\frac{1}{n_k}\sum_{j \in c_k}\frac{\alpha'_{qi}}{2} \tag{14}$$

Let P'_j be the quality score for each project *j*, where

$$\text{P}'_j \in \{7, 8, 9, 10\} \text{ and } j = \{1, 2, 3, 4\}$$
$$\begin{aligned} P'_1 &= 7 \\ P'_2 &= 8 \\ P'_3 &= 9 \\ P'_4 &= 10 \end{aligned} \tag{15}$$

For projects denoted as P'_1, 6 projects are available.

For projects denoted as P'_2, 8 projects are available.

For projects denoted as P'_3, 7 projects are available.

For projects denoted as P'_4, 3 projects are available.

In all, there is a total of 24 projects available.

Let Q'_{ij} be the rehabilitation score, which is the difference between the quality scores for project *j* and commune *i*.

$$\begin{aligned} Q'_{ij} &= (P'_j - C'_i) \in \mathbb{R} \\ \text{and } \quad i &= \{1, \ldots, 47\},\ j = \{1, 2, 3, 4\} \end{aligned} \tag{16}$$

Table 6 illustrates the rehabilitation scores for each project–commune combination. Therefore, the model uses the following 188 pre-defined sets (coefficients).

Table 6. Rehabilitation Scores Q'_{ij}

Q'_{ij}	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9	i=10
j=1	1.82	0.62	1.52	0.85	-0.14	1.54	2.48	0.65	1.06	0.18
j=2	2.82	1.62	2.52	1.85	0.86	2.54	3.48	1.65	2.06	1.18
j=3	3.82	2.62	3.52	2.85	1.86	3.54	4.48	2.65	3.06	2.18
j=4	4.82	3.62	4.52	3.85	2.86	4.54	5.48	3.65	4.06	3.18

Q'ij	i=11	i=12	i=13	i=14	i=15	i=16	i=17	i=18	i=19	i=20
j=1	2.74	3.65	0.56	2.33	2.96	2.15	2.47	0.85	0.36	0.73
j=2	3.74	4.65	1.56	3.33	3.96	3.15	3.47	1.85	1.36	1.73
j=3	4.74	5.65	2.56	4.33	4.96	4.15	4.47	2.85	2.36	2.73
j=4	5.74	6.65	3.56	5.33	5.96	5.15	5.47	3.85	3.36	3.73

Q'ij	i=21	i=22	i=23	i=24	i=25	i=26	i=27	i=28	i=29	i=30
j=1	1.86	0.07	1.69	1.50	1.70	0.90	1.34	2.05	2.67	1.33
j=2	2.86	1.07	2.69	2.50	2.70	1.90	2.34	3.05	3.67	2.33
j=3	3.86	2.07	3.69	3.50	3.70	2.90	3.34	4.05	4.67	3.33
j=4	4.86	3.07	4.69	4.50	4.70	3.90	4.34	5.05	5.67	4.33

Q'ij	i=31	i=32	i=33	i=34	i=35	i=36	i=37	i=38	i=39	i=40
j=1	-1.71	0.90	2.39	-0.03	1.80	-1.07	3.36	1.90	1.95	0.31
j=2	-0.71	1.90	3.39	0.97	2.80	-0.07	4.36	2.90	2.95	1.31
j=3	0.29	2.90	4.39	1.97	3.80	0.93	5.36	3.90	3.95	2.31
j=4	1.29	3.90	5.39	2.97	4.80	1.93	6.36	4.90	4.95	3.31

Q'ij	i=41	i=42	i=43	i=44	i=45	i=46	i=47
j=1	1.99	1.30	3.21	1.61	0.88	0.33	1.38
j=2	2.99	2.30	4.21	2.61	1.88	1.33	2.38
j=3	3.99	3.30	5.21	3.61	2.88	2.33	3.38
j=4	4.99	4.30	6.21	4.61	3.88	3.33	4.38

Equation 16 allows the analyst to calculate the rehabilitation scores Q'_{ij}, which are located in Table 6. When AFRICOM assigns a project *j* to commune *i*, the commune rehabilitates up to the quality score of project *j*. For example, in the top-left corner of the table, the analyst would make the following calculation (see Appendix D, Section I):

$$Q'_{11} = (P'_1 - C'_1) \in \mathbb{R} \ \therefore \ Q'_{11} = (7.00 - 5.18) = 1.82$$

c. *Decision Variables*

The optimization model uses x'_{ij} for its decision variables.

Let x'_{ij} be the binary decision variable,

$$\text{where } x'_{ij} = \begin{cases} 1 & \text{if project } P'_j \text{ is assigned to commune } i \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

$$\text{and } \quad i = \{1, \ldots, 47\},\ j = \{1, 2, 3, 4\}$$

d. Objective Function

The objective function maximizes the total value of rehabilitation.

$$Max = \sum_{j=1}^{4}\sum_{i=1}^{47} Q'_{ij}x'_{ij} \tag{18}$$

e. Constraints

Equation 19 is a covering constraint ensuring that each commune *i* is served by at least one project *j*.

$$\sum_{\forall i \in Si'i} x'_{ij} \geq 1, \forall i \tag{19}$$

For example, when the set-covering constraint is applied to commune 1, it reads as follows (see Appendix H for all 47 set-covering constraints):

Covering, *commune* 1 is served by a project(s)

$$(x'_{1j} + x'_{2j} + x'_{32j} + x'_{34j} + x'_{46j}) \geq 1$$

Equations 20 to 23 are supply constraints ensuring that every project *j* is assigned to at most one commune *i*.

$$\sum_{\forall i} x'_{i1} = 6 \tag{20}$$

$$\sum_{\forall i} x'_{i2} = 8 \tag{21}$$

$$\sum_{\forall i} x'_{i3} = 7 \tag{22}$$

$$\sum_{\forall i} x'_{i4} = 3 \tag{23}$$

For example, when the supply constraint is applied to project design 1, it reads as follows (see Appendix H for the details of all four supply constraints):

Supply of project $j = 1$, of which 6 are available

$$\begin{pmatrix} x'_{11} + x'_{21} + x'_{31} + x'_{41} + x'_{51} + x'_{61} + x'_{71} + x'_{81} + x'_{91} + x'_{101} + x'_{111} + x'_{121} + x'_{131} + \\ x'_{141} + x'_{151} + x'_{161} + x'_{171} + x'_{181} + x'_{191} + x'_{201} + x'_{211} + x'_{221} + x'_{231} + x'_{241} + x'_{251} + \\ x'_{261} + x'_{271} + x'_{281} + x'_{291} + x'_{301} + x'_{311} + x'_{321} + x'_{331} + x'_{341} + x'_{351} + x'_{361} + x'_{371} + \\ x'_{381} + x'_{391} + x'_{401} + x'_{411} + x'_{421} + x'_{431} + x'_{441} + x'_{451} + x'_{461} + x'_{471} \end{pmatrix} = 6$$

Equation 24 is the demand constraint ensuring that every commune *i* receives at most one project *j*.

$$\sum_{\forall j} x'_{ij}, \forall i \tag{24}$$

For example, when the demand constraint is applied to Commune 1, it reads as follows (see Appendix H for the details of all 47 demand constraints):

$$\text{Demand from } \textit{commune } 1 \text{ for project } j \quad (x_{11} + x_{12} + x_{13} + x_{14}) \leq 1$$

Equation 25 is a brute demand constraint that assigns at least one project *j* to each of the following high-threat communes (HTC): 7, 9, 10, 15, 17, 20, 24, and 32.

$$\sum_{\forall j} x'_{ij} \geq 1, \forall i \in HTC' \tag{25}$$

For example, when the brute constraint (or HTC) is applied to commune 7, it reads as follows (see Appendix H for the details of all eight HTC constraints):

$$\sum_{j=1}^{4} x'_{7j} \geq 1$$

Equation 26 is a binary constraint, which forces the analyst to select or reject (1 or 0) the assignment of a project *j* to a commune *i*.

$$x'_{ij} = 1 \text{ or } 0, \forall ij \tag{26}$$

3. Limitations

Like Model I, the first limitation deals with the objective function, maximizing the allocation of projects to communes *i* based on rehabilitation scores and subject to multiple constraints (Equations to 19 to 26). Although Model II is a slight modification of Model I, Model II has the following distinctions:

1. The communes' quality score c_i in Equation 1 changed to c'_i, which attempts to indicate the interrelatedness (or realm of influence) with the neighboring communes' eight sustainable-development factors α'_{qi}.

2. Model II does not include the covering constraints from Model I.

The second limitation to Model II is its yes-or-no output or decision-modeling approach.

D. MATERIALS

The input data originated from multiple sources of unclassified websites—the World Bank Group, City Population, online media websites, and other online sources that provided unclassified maps of the threat situation. The World Bank Group's data are current as of May 2014.[79] City Population compiled its data, as of 2009, from the United Nations World Population and Housing Census Program.[80] The data from both organizations' websites cover all 87 of the communes (or municipalities, which are the lowest tier of the administrative hierarchy) located in the regions of Tombouctou, Kidal, and Gao in Northern Mali. However, to simplify the problem set, the decision analyst may opt to combine groups of small communes into a single site to create a more manageable site bank. For this scenario, the analyst assumes a total of 47 project sites, which are still referred to as communes.

For Model I, analysts use the following criteria for c_i (see Appendix D):

$\alpha_{i1} = [0,1] =$ population density

$\alpha_{i2} = [0,1] =$ existing bodies of water

$\alpha_{i3} = [0,1] =$ flood frequency

$\alpha_{i4} = [0,1] =$ drought mortality risk

$\alpha_{i5} = [0,1] =$ cropland intensity

$\alpha_{i6} = [0,1] =$ illicit routes

$\alpha_{i7} = [0,1] =$ violent NSA-controlled territory

$\alpha_{i8} = [0,1] =$ significant activities (SIGACTS)

For Model II, analysts use the following criteria for c'_i:

$\alpha'_{i1} = [0,1] =$ population density

79 The World Bank Group, *World Bank Climate Variability Tool.*

80 City Population, "Population Statistics for Countries."

$\alpha'_{i2} = [0,1] =$ existing bodies of water

$\alpha'_{i3} = [0,1] =$ flood frequency

$\alpha'_{i4} = [0,1] =$ drought mortality risk

$\alpha'_{i5} = [0,1] =$ cropland intensity

$\alpha'_{i6} = [0,1] =$ illicit routes

$\alpha'_{i7} = [0,1] =$ violent NSA-controlled territory

$\alpha'_{i8} = [0,1] =$ significant activities (SIGACTS)

E. METHOD

For Model I, there are 188 decision variables and 108 constraints used to allocate projects and determine rehabilitation scores, exceeding the computing capabilities of Microsoft Excel's basic Solver add-in, which allows the user to apply 200 decision variables and 100 constraints (see Appendix H). Therefore, Model I requires an upgrade to an advanced solver engine. For Model II, there are 188 decision variables and 61 constraints used to allocate projects and determine rehabilitation scores, which do not exceed Solver's computing capabilities. For both models, this research used Frontline Systems' Risk-Solver Platform (RSP), a solver add-in that interfaces with Excel and uses a variety of built-in solver engines.[81] The RSP add-in enhances the analyst's ability to handle significantly more decision variables and constraints, as detailed in Appendix H.[82]

[81] Frontline Systems, "Frontline Solvers Built-in Solver Engines," Frontline Systems, accessed May 15, 2014, http://www.solver.com/files/_document/Built–in–Solver–Engine–Comparison–Chart.pdf. This scenario uses the Large–Scale LP/QP Solver Engine to calculate more complex problems.

[82] Frontline Systems, "Large-Scale LP/QP Solver Engine," Frontline Systems, accessed May 15, 2014, http://www.solver.com/large–scale–lpqp–solver–engine.

VII. RESULTS, ANALYSIS, AND SYNTHESIS

This chapter presents Step IV-B (solve) and Step IV-C (interpret) in the decision-support process: developing and testing solutions, analyzing results, implementing results, and updating. In addition, this chapter seeks to answer the primary research questions, while addressing the following subordinate questions:

1. Do sustainable-development projects increase the compliance of NSAs and eventual displacement of VEOs?
2. What are the benefits of investing in development to support theater campaign plans, economic development, and indigenous security forces?
3. How can sustainable development help build our capacity to strengthen African partner nations?

Figure 10 highlights the importance of a feedback loop in the decision-support process.

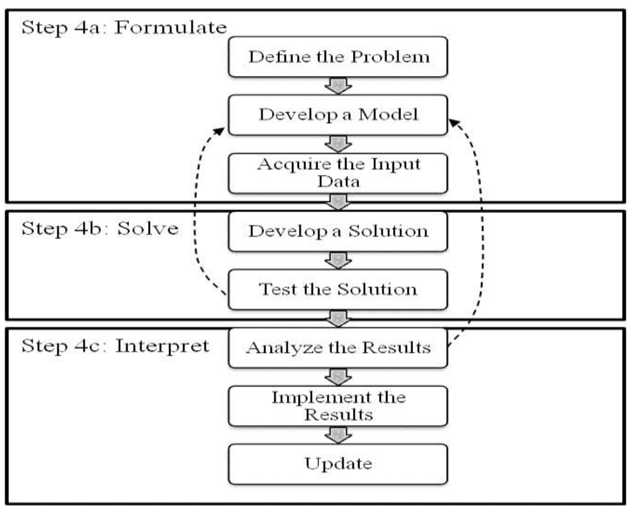

Figure 10. Step IV: A Framework to Support Decision Makers

A. OVERVIEW

This chapter presents results and analyses for Model I and Model II and includes the diplomatic estimations proposed in Chapter IV. The diplomatic estimation evaluates the amount of control the Malian government may potentially regain by allocating projects optimally. Analysts indicate the amount of control by summing the total area of the communes *i*, which are assigned projects *j*, and divide them by the total area of the region in which the communes are found.[83] To clarify the notion of control, analysts may adapt the following definitions. Details of the project designs are in Appendix C.

Project Design 1, the analyst assumes the following:

1. Department of State (DOS)-led projects focus strongly on sustainable development; control is determined by the populace's compliance with the government.
2. The degree to which the government can maintain a permissive to uncertain environment is low,[84] as is its ability to maintain a low VEO threat level.
3. Zero to negligible use of external security/military forces (e.g., French and U.S.) is desired; instead, the indigenous security apparatus polices itself.

For Project Design 2, the analyst assumes the following:

1. DOS-led projects focus strongly on sustainable development; control is determined by the populace's compliance with the government.
2. The degree to which the government can maintain a permissive to uncertain environment is low, as is its ability to maintain a low VEO threat level.
3. Minimal use of external security/military forces (e.g., French and U.S.) is desired; instead, the indigenous security apparatus polices itself.

For Project Design 3, the analyst assumes the following:

1. DOD- and DOS-led projects focus moderately on development.
2. The hostility in the environment is uncertain; the VEO threat is moderate to high.
3. Moderate use of external security or military forces (e.g., Economic Community of the West African States [ECOWAS]) is desirable.

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[83] Ibid. Mali consists of eight regions and the Bamako capital district. However, this thesis focuses on three regions. There are a total of 87 communes in Northern Mali; however, this thesis simplified the problem into 47 sites, which are still called communes.

[84] The level of permissiveness in a commune is determined by assessing the operational environment. According to JP 1-02, the operations environment is a composite of the conditions, circumstances, and influences that affect the employment of military forces and bear on the decisions of the unit commander. A permissive environment suggests that the operational environment in which the host country military and law enforcement agencies have control and the intent and capability to assist operations that a unit intends to conduct. An uncertain environment suggests that the operational environment in which host government forces, whether opposed to or receptive to operations that a unit intends to conduct, do not have totally effective control of the territory and population in the intended area of operations. A hostile environment suggests that the operational environment in which hostile forces have control and the intent and capability to effectively oppose or react to the operations a unit intends to conduct. Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms* (Arlington, VA: Department of Defense, 2014).

For Project Design 4, the analyst assumes the following:

1. DOD-led projects focus moderately on development.
2. The environment is hostile; VEO threat is high.
3. Overt employment of security and military forces (e.g., Malian Defense Forces, ECOWAS, French, coalition support) is desirable.

B. MODEL I: RESULTS AND ANALYSIS

Table 7 illustrates the allocation of projects *j*, the rehabilitation scores Q_{ij} by region, increases in rehabilitation, and the amount of control regained.

Table 7. Model I: Allocation of Sustainable-Development Projects

Regions		*j=1*	*j=2*	*j=3*	*j=4*	Q_{ij}	*Rehab (Δ%)*	*Control (%)*	Total No. Projects *j*
Gao	*i={1,…,14}*	0	2	3	2	31.0	96.9%	71.7%	**7**
Kidal	*i={15,…,25}*	0	3	3	0	21.0	70.0%	65.7%	**6**
Tombouctou	*i={26,…,47}*	6	3	1	1	31.3	58.1%	60.2%	**11**
Northern Mali	*i={1,…,47}*	6	8	7	3	83.3	71.9%	65.7%	**24**

In the Gao region, the total rehabilitation score increased by 96.9 percent (i.e., c_i increased from 32.0 to 63.0), and the government potentially controls 71.7 percent of the political space. The model allocated seven projects as follows:[85]

1. For Project Design 2, Gao received two projects.
2. For Project Design 3, Gao received three projects.
3. For Project Design 4, Gao received two projects.

Kidal's total rehabilitation score increased by 70.0 percent (i.e., c_i increased from 30.0 to 51.0). The focus was mostly DOS-sponsored projects. Therefore, the government potentially controls 65.7 percent of the political space. The model allocated six projects as follows:

1. For Project Design 2, Kidal received three projects.
2. For Project Design 3, Kidal received three projects.

Tombouctou's total rehabilitation score increased by 58.1 percent (i.e., c_i increased from 53.8 to 85.1). The main focus was DOS-sponsored projects. Therefore,

[85] The mix of DOD-led and DOS-led project designs was evenly distributed in terms of DOD and DOS sharing the lead.

the government potentially controls 60.2 percent of the political space. The model allocated 11 projects as follows:

1. For Project Design 1, Tombouctou received six projects.
2. For Project Design 2, Tombouctou received three projects.
3. For Project Design 3, Tombouctou received one project.
4. For Project Design 4, Tombouctou received one project,

C. MODEL II: RESULTS AND ANALYSIS

Table 8 illustrates an allocation of projects *j*, rehabilitation scores Q_{ij} by region, increases in rehabilitation, and amount of control regained.

Table 8. Model II: Allocation of Sustainable-Development Projects

Regions		*j=1*	*j=2*	*j=3*	*j=4*	Q'_{ij}	*Rehab* (Δ%)	*Control* (%)	Total No. Project *j*
Gao	*i={1,…,14}*	0	4	3	0	24.3	69.8%	73.8%	7
Kidal	*i={15,…,25}*	3	2	2	0	19.4	54.4%	55.6%	7
Tombouctou	*i={26,…,47}*	3	2	2	3	37.2	77.9%	17.1%	10
Northern Mali	*i={1,…,47}*	6	8	7	3	80.9	68.5%	45.5%	24

Gao's total rehabilitation score increased by 69.8 percent (i.e., c_i increased from 34.7 to 59.0). The mix of DOD- and DOS-led project designs was evenly distributed in terms of DOD and DOS taking the lead. Therefore, the government potentially controls 73.8 percent of the political space. The model allocated seven projects as follows:

1. For Project Design 2, Gao received four projects.
2. For Project Design 3, Gao received three projects.

Kidal's total rehabilitation score increased by 54.4 percent (i.e., c_i increased from 35.6 to 55.0). The focus was DOS-sponsored projects. Therefore, the government potentially controls 55.6 percent of the political space. The model allocated seven projects as follows:

1. For Project Design 1, Kidal received three projects.
2. For Project Design 2, Kidal received two projects.
3. For Project Design 3, Kidal received two projects.

Tombouctou's total rehabilitation score increased by 77.9 percent (i.e., c_i increased from 47.8 to 85.0). The mix of DOD- and DOS-led project designs was evenly distributed in terms of DOD and DOS taking the lead. Therefore, the government potentially controls 17.1 percent of the political space. The model allocated 10 projects as follows:

1. For Project Design 1, Tombouctou received three projects.
2. For Project Design 2, Tombouctou received two projects.
3. For Project Design 3, Tombouctou received two projects.
4. For Project Design 4, Tombouctou received three projects.

D. SYNTHESIS

> Desertification is a silent, invisible crisis that is destabilizing communities on a global scale. As the effects of climate change undermine livelihoods, inter-ethnic clashes are breaking out within and across states and fragile states are turning to militarization to control the situation. The effects of desertification are increasingly felt globally as victims turn into refugees, internally displaced people and forced migrants or they turn to radicalization, extremism or resource-driven wars for survival. If we are to restore peace, security and international stability in a context where changing weather events are threatening the livelihoods of more and more people, survival options are declining and state capacities are overburdened, then more should be done to combat desertification, reverse land degradation and mitigate the effects of drought. Otherwise, many small-scale farmers and poor, land dependent communities face two choices: fight or flight.[86]

The models allocated projects in a significantly different manner, but Model I and Model II produced similar rehabilitation scores (i.e., 83.3 vs. 80.9, respectively). Specifically, Model I was better at allocating and matching projects to communes based on threat level, degradation, and achieving maximal rehabilitation (see Figure 11). Ultimately, the set-covering constraints allowed Model I to effectively allocate projects and achieve greater rehabilitation. See Table 9 for a comparison of the models.

Additionally, Model II misallocated Project Design 4 by assigning all three of them to the Tombouctou region. However, the Kidal and Gao regions had a greater need

[86] United Nations Convention to Combat Desertification, "Desertification: The Invisible Frontline," 1.

for Project Design 4. In the end, Model I allocated the projects while addressing the following supplemental research questions posed in chapters I and VII:

1. Do sustainable-development projects increase the compliance of NSAs and eventual displacement of VEOs?
2. What are the benefits of investing in development to support theater campaign plans, economic development, and indigenous security forces?
3. How can sustainable development help build capacity to strengthen African partner nations?

With the assignment of sustainable-development projects to key communes, the projects potentially facilitate the following:

1. Creation of jobs for NSAs focused on development (e.g., agriculture, strategic oases, irrigated lands, livestock, and project security)
2. Rehabilitation of rural areas to reestablish traditional nomadic lifestyles
3. Improvement of infrastructure and basic services in rural areas
4. Increase of collaboration between the DOS and DOD

Table 9. Model I Versus Model II

COA-1: Model I "Set Covering"

Regions		$j=1$	$j=2$	$j=3$	$j=4$	Q_{ij}	Rehab (Δ%)	Control (%)	Total No. Projects j
Gao	$i=\{1,\ldots,14\}$	0	2	3	2	31.0	96.9%	71.7%	7
Kidal	$i=\{15,\ldots,25\}$	0	3	3	0	21.0	70.0%	65.7%	6
Tombouctou	$i=\{26,\ldots,47\}$	6	3	1	1	31.3	58.1%	60.2%	11
Northern Mali	$i=\{1,\ldots,47\}$	6	8	7	3	83.3	71.9%	65.7%	24

COA-2: Model II "Realm of Influence"

Regions		$j=1$	$j=2$	$j=3$	$j=4$	Q'_{ij}	Rehab (Δ%)	Control (%)	Total No. Project j
Gao	$i=\{1,\ldots,14\}$	0	4	3	0	24.3	69.8%	73.8%	7
Kidal	$i=\{15,\ldots,25\}$	3	2	2	0	19.4	54.4%	55.6%	7
Tombouctou	$i=\{26,\ldots,47\}$	3	2	2	3	37.2	77.9%	17.1%	10
Northern Mali	$i=\{1,\ldots,47\}$	6	8	7	3	80.9	68.5%	45.5%	24

For Model I, the overall amount of control regained in Northern Mali is 65.7 percent. In addition, the projects increase the communes' level of land quality (i.e., reversed land degradation) by 71.9 percent. The advantages of COA I are its ability to rehabilitate communes and regain control throughout Northern Mali. As indicated by the red circles in Table 9, COA I appears to more optimal in terms of rehabilitation and control. As compared to Model II, the major advantage of Model I is the significant control regained in Tombouctou (60.2 percent in Model I versus 17.1 percent in Model II). See Figure 11 for a visual analysis.

For Model II, the overall amount of control regained in Northern Mali is 45.5 percent. Additionally, the projects increase the level of land quality by 68.5 percent. Like COA I, Model II provides coverage throughout Northern Mali. However, the overall amount of control regained in Tombouctou is 17.1 percent.

Finally, as AFRICOM refines Model I,[87] it should ensure the optimal solution nests with QDDR objectives before collaborating with the U.S. ambassador to Mali:[88]

1. Build U.S. civilian power, bringing together the unique contributions of civilians across the federal government to advance U.S. interests.
2. Elevate and transform development to deliver results by focusing our investments, supporting innovation, and measuring results.
3. Build a civilian capacity to prevent and respond to crisis and conflict and give our military the partner it needs and deserves.
4. Change the way we do business by working smarter to save money, planning and budgeting to accomplish our priorities, and measuring the results of our investments.

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[87] The refined model should include updated input data from negotiations, mediations, and consensus building meetings. Also, surveyors should increase the accuracy of the data to reflect the current levels of threat, land degradations, and so forth. Finally, the analysis should use the results from the sensitivity analyses to rerun Model I for better accuracy.

[88] U.S. Department of State, *Quadrennial Diplomacy & Development Review: A Summary*.

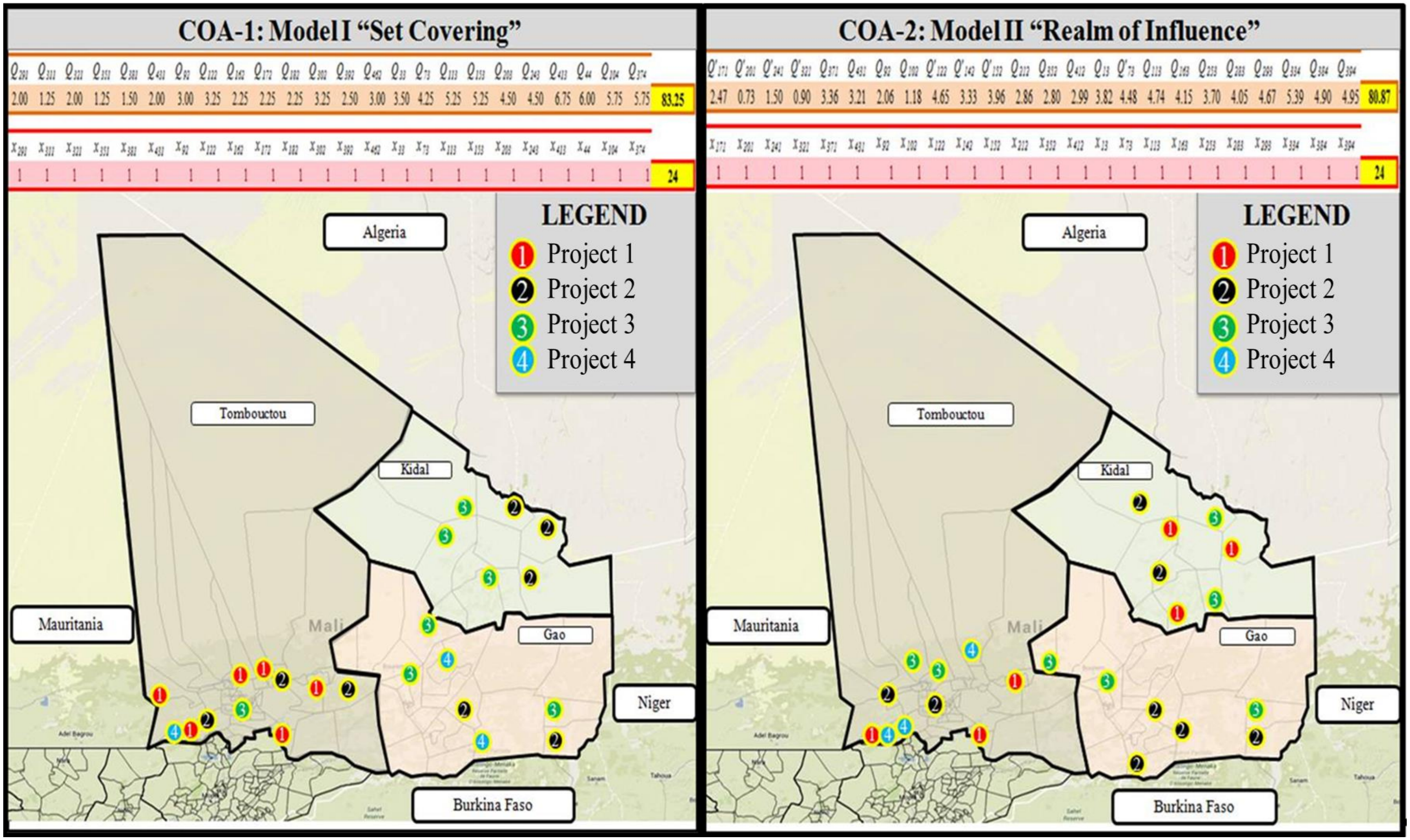

Figure 11. Visual Analysis: Model I Versus Model II

E. SENSITIVITY ANALYSIS: MODEL I SET COVERING

Like any real-world scenario, the objective function coefficients (OFCs) carry uncertainty. Commune and project scores are not likely to be static or fixed. Therefore, the analyst should evaluate the sensitivity of the optimal solution from Model I by making reasonable changes to the OFC values and analyzing the effects. In the absence of accurate data, a simulation-based sensitivity analysis of the input variables should assist the decision analyst in maximizing rehabilitation and optimally allocating projects.[89] The simulation forecasts the rehabilitation scores by comparing two extreme scenarios to one another (i.e., a maximum case vs. minimum case) and to a most-likely-case scenario. In this setup, the Monte Carlo simulation ran five trials (one-thousand times per trial) for each project design.

The simulation assumes three development scenarios that affect project scores (i.e., minimum, most likely, and maximum scores), which lower as the threat level increases.[90] Due to the uncertainty surrounding the threat level in Northern Mali, each of these scenarios has an equal chance of happening (i.e., a uniform distribution—see Appendix E). Concurrently, the simulation addresses three commune scenarios (minimum, most likely, and maximum scores), which lower as the threat level increases. In this case, the simulation assumes a triangular distribution, as explained in Appendix E. The triangular distribution is a continuous probability distribution with minimum, maximum, and most-likely scores for projects and communes. Table 10 contains a summary of rehabilitation scores and illustrates different rehabilitation scores for minimum, most-likely, maximum, and average situations.

[89] A sensitivity analysis allows the analyst to simulate the uncertainty in the output of the IP models. The analyst can simulate the apportionment of scores along different conditions of uncertainty. Therefore, the sensitivity analysis allows the analyst to test the robustness of the IP models' outputs in the case of uncertainty. Furthermore, analysts can test the relationships between input variables and the output variables in the IP model. Commensurate with this thesis, analysts can clarify their interpretation of the IP models so that decision makers better understand the strength of the model as they collaborate with policymakers. This added level of analysis lends more credibility to the IP models, and it may give the AFRICOM commander more influence with the U.S. ambassador to Mali.

[90] The Monte Carlo method's core idea is to use random samples of parameters or inputs to explore the behavior of a complex system or process. This Monte Carlo simulation was used to make forecasts due to uncertainty. Otherwise, the IP model could be significantly inaccurate with adverse effects. Frontline Systems, "Large–Scale LP/QP Solver Engine," Frontline Systems, accessed May 15, 2014, http://www.solver.com/large–scale–lpqp–solver–engine.

Table 10. Sensitivity Analysis: Initial Setup of Input Variables

Project Design 1

	No. Proj	Proj Score	Commune Score	Rehab Score
max case	6	6.01	1.42	27.54
most likely case	5	6.50	1.67	24.15
min case	4	7.00	1.92	20.32
		Monte Carlo Simulation Results for Project Desgin 1		24.17

Project Design 2

	No. Proj	Proj Score	Commune Score	Rehab Score
max case	8	7.01	2.47	36.32
most likely case	7	7.50	2.72	33.46
min case	6	8.00	2.97	30.18
		Monte Carlo Simulation Results for Project Desgin 2		33.49

Project Design 3

	No. Proj	Proj Score	Commune Score	Rehab Score
max case	7	8.01	4.61	23.80
most likely case	6	8.50	4.86	21.84
min case	5	9.00	5.11	19.45
		Monte Carlo Simulation Results for Project Desgin 3		21.86

Project Design 4

	No. Proj	Proj Score	Commune Score	Rehab Score
max case	3	9.01	5.75	9.78
most likely case	2	9.50	5.83	7.34
min case	1	10.00	6.00	4.00
		Monte Carlo Simulation Results for Project Desgin 4		7.29

	max case	*most likely case*	*min case*	*on avg*
Rehab Scores by Scenario	97.44	86.79	73.95	86.81

Table 10 illustrates the initial setup of the input variables evaluated in the simulation. The resultant rehabilitation scores shown in the table originate from the starting values for each scenario.[91] Ultimately, the simulation suggests a total maximum rehabilitation score of 86.8 on average (see the outputs highlighted in the black ribbons). The minimum, most-likely, and maximum cases yielded the following scores: 97.4, 86.8, and 74.0, respectively.

According to the simulation, to achieve a total maximum rehabilitation score of 86.8 (the most-likely scenario), AFRICOM would allocate 20 projects in the following fashion:

1. For Project Design 1, AFRICOM allocates five projects to achieve a rehabilitation score of 24.2. On average, the project and commune scores are approximately 6.50 and 1.67 respectively.
2. For Project Design 2, AFRICOM allocates seven projects to achieve a rehabilitation score of 33.5. On average, the project and commune scores are approximately 7.50 and 2.72 respectively.
3. For Project Design 3, AFRICOM allocates six projects to achieve a rehabilitation score of 21.9. On average, the project and commune scores are approximately 8.50 and 4.86 respectively.
4. For Project Design 4, AFRICOM allocates two projects to achieve a rehabilitation score of 7.29. On average, the project and commune scores are approximately 8.50 and 5.83 respectively.

The sensitivity analysis shows that Model I uses conservative values. For example, Model I assumes an allocation of 24 projects to achieve a total maximum rehabilitation score of 83.3. However, the simulation suggests that AFRICOM can achieve a higher rehabilitation score of 86.8 with only 20 projects. Ultimately, the analyst would need to take the findings from this sensitivity analysis and conduct another for the outputs for Model I—an endeavor beyond the scope of this thesis.

[91] The simulation would randomly select the project number, project score, and commune score based on the aforementioned distributions (i.e., uniform and triangular distributions). However, Table 10 merely illustrates the initial setup of the simulation, and it shows the resultant outputs without simulation functions. For example, Risk Solver Platform uses the =PsiTriangular() function for the triangular distribution. Therefore, the simulator uses this function to draw a sample from a continuous distribution (e.g., for Project Design 1, project scores range 9.01 to 10.0 and commune scores range 5.75 to 6.00).

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VIII. CONCLUSION, RECOMMENDATIONS, AND FUTURE RESEARCH

A. CONCLUSION AND RECOMMENDATIONS

AFRICOM, a relatively new organization, continues to face overwhelming DIMEFIL challenges in Northern Mali under the combined effects of the U.S. sequestration and continuing resolutions. Ultimately, AFRICOM must expand its alternatives by considering indirect approaches, such as sustainable development, to prevent further erosion of Mali's ability to provide security, strong governance, economic growth, and regional stability. If not, VEOs and violent NSAs will continue to seize opportunities and spread their influence across the Sahel region.

The ability to understand and penetrate the adversary's decision cycles is vital. To deter, compel, or show restraint, the DOD, DOS, and interagencies must collaborate to determine optimal deterrence alternatives. Since violent NSAs are not inert pieces on a board game, decision analysts must make careful recommendations to prevent U.S. leaders from acting upon a misapprehension that they can exact decisive, direct influence over their adversary.

Overall, the decision-support process described in this thesis leads to a recommended allocation of sustainable-development projects for regaining control of Northern Mali. The BIP models allocate projects to key locations to combat desertification and control ungoverned territories, and a solution that incorporates a mixture of four project designs for AFRICOM to pursue is identified. In the end, the decision maker has two COAs under which to allocate projects. However, the model is highly adaptable as indicated by the equations in Chapter VI. For example, the equations are written such that the analyst could further divide Mali into more or fewer communes. Also the analyst could add more project designs to address different needs, interests, and concerns of the indigenous populations of the Sahel.

For COA I (or Model I), the overall amount of control regained is 65.7 percent of Northern Mali. Taken as a whole, COA I appears to be a better model in terms of maximizing rehabilitation and control. For COA II (or Model II), the overall amount of control regained is 45.5 percent. However, Model II fails to control Tombouctou adequately (17.1 percent).

Although only 24 of 47 communes received a project, the decision-support process suggests an indirect approach to target VEOs in ways that satisfy the U.S. ambassador and the AFRICOM commander without risk to human life or American interests. The author recommends that AFRICOM nest its strategy with the policies of the U.S. ambassador, S-AF and S-NEA and explore long-term, sustainable development to increase influence and achieve U.S. interests under a whole-of-government approach.

B. AREAS FOR FUTURE RESEARCH

This thesis proposes a decision-support process, using Northern Mali as a pilot case. Ideally, the entire trans-Sahara would be modeled to incorporate external factors such as the conflicts in Libya, Algeria, Niger, and Mauritania. As one example, the CT and security operations that Algeria had conducted for over a decade have caused al-Qaida in the Islamic Maghreb (AQIM) to move to the ungoverned territories of the trans-Sahara, where the regional security apparatus is weaker and VEO networks and infrastructure are robust. Thus, if other countries were included in the model, the optimal allocation of projects would increase significantly.[92] Furthermore, this larger-scale model would operate under the assumption that the U.S. national-security system (the DOD, DOS, and other interagency elements) are fully cooperating and collaborating.

In the near term, AFRICOM analysts should collect more accurate input data to enhance BIP models, which have the flexibility to take on more sustainable-development and threat factors. For example, after conducting site surveys, a decision analyst could add the sustainable development promoted by the United Nations (UN).[93] The author recommends that analysts conduct more thorough sensitivity analysis of model inputs,

[92] Effects-based targeting would be more effective as well. The DOS and DOD can collaborate to deter, displace, and defeat VEOs. If the Trans Saharan countries work together, they can purposefully displace VEOs in one location and destroy or defeat them in another location—by design. As VEOs retreat to their safe havens, and the African governments prove they can support the populace, they will likely gain more compliance form their citizens and regain control of the ungoverned or under governed territories.

[93] United Nations, *2012 FAO Statistical Yearbook: Chapter 4—Sustainability Dimensions.*

processes, and outputs and work with the DOS and USAID to refine model constraints. By collaborating with interagency and international organizations, AFRICOM may enhance the accuracy of the models, and by working with the interagency to negotiate with key stakeholders, including leaders of indigenous populations and tribal groups, AFRICOM may gain more accurate data and private information.

The author recommends that future models include budget constraints and cost–benefit analysis—considering the financial aspects of sustainable development will make the model more realistic. Currently, a decision analyst might develop the model with an operating-budget range of $14 to $84 million.[94] Adding realistic budgeting would provide more authority and persuasiveness to the AFRICOM commander as he collaborates with the embassy.

Finally, future research should include rogue states and the support they give to violent NSAs and consider additional non-state-actors (e.g., intergovernmental organizations, private organizations, and NGOs) as having multiple competitors in the game better simulates real-world scenarios. In the end, decision analysts can only estimate the intentions of VEOs and violent NSAs in determining the critical variables and preferences that will eventually shape the operating environment. Adding these factors would make the exploration of other deterministic models or probabilistic models more complex and realistic.

[94] The U.S. announced plans to provide approximately $84 million to support the African-led International Support Mission to Mali (AFISMA) for the rest of fiscal year 2014. Recall in Chapter IV, the U.S. spent nearly $14 million in Mali to support TSCTP in 2007. So far in 2014, the U.S. has already committed over $12 million to provide basic logistical support to Economic Community of West African States (ECOWAS) forces. Also, decision analysts would take into account the representatives of the U.S.'s Africa Contingency Operations Training & Assistance (ACOTA) program are in West Africa working with troop contributing countries (Benin, Burkina Faso, Ghana, Niger, Nigeria, Senegal, and Togo) to conduct needs assessments and prepare for training. Mary Beth Leonard, "U.S. Ambassador to the Republic of Mali: Embassy's Bilateral Assistance Programs," accessed September 6, 2014, http://mali.usembassy.gov/statement_09062013.html.

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APPENDIX A. STEP I–FRAME: A WICKED PROBLEM

In the age of networked intelligence, how prepared are policymakers and military commanders for dealing with conflicts as power shifts to individuals, networks, and coalitions in a multi-polar world?[95] More importantly, how might analysts tackle wicked problems, which pose significant looming challenges to the U.S. national security system? In response to national security interests and defense priorities, analysts must consider the diffusion of power, dimension of morality, and social contextual issues in the Northern Mali conflict.

To determine whether the case of Northern Mali is in wicked problem territory, this analysis explores the efficacy of the PMESII-PT analytic tool (i.e., assessing the following metrics: political, military, economic, social, information, infrastructure, physical environment and time), which serves to supplement the design approach to discover feasible solutions and strategies. With this crucial distinction, decision analysts should be wary of making promises of solving, taming, or even coping with wicked problems. With existing tools of analysis, analysts gain an adequate handle on the vast array of problems and cascading effects over an indefinite period of time. Although conventional approaches have proven to solve complex problems, analysts must acknowledge that rational analytic methods alone insufficiently tackle wicked problems. Therefore, in the age of networked intelligence, analysts require innovative methods of problem solving to address the interdependencies associated with wicked problems. Ultimately, with collaborative networks, analysts can leverage an approach that ably identifies activities, applies innovation, exercises systems thinking, and enhances their efforts with information technologies to tackle wicked problems and collaborative strategies.

95 U.S. National Intelligence Council, *Global Trends 2030: Alternative Worlds* (Washington, DC: National Intelligence Council, 2012). http://globaltrends2030.files.wordpress.com/2012/11/global–trends–2030–november2012.pdf, ii. The author poses this question based on the findings in the GT–2030 report.

A. USING SUPPLEMENTAL ANALYTIC TOOLS

To determine whether a conflict is in wicked problem territory, an activity map is a constructive tool to discover the degree at which problems, solutions, and stakeholders interact (see Figure 12). If the map illustrates uncertainty and a great degree of variance in a problem statement, decision analysts are approaching the realm of wicked problem territory. Consequently, with an undistinguished appraisal of the problem, the range of possible solutions is inexhaustible. To compound the situation, the constraints of the problem space relentlessly evolve throughout the domains of PMESII-PT. Due to the volatility created by many stakeholders, the limitations of the PMESII-PT domains are dynamic and beyond complexity. Figure 12 illustrates the aforementioned activity map.

Figure 12. Activity Map: Wicked Problem Territory

B. THE CONFLICT IN NORTHERN MALI

In late March 2012, the following groups took Mali by storm: (1) National Committee for the Restoration of Democracy and State (CNRDR), (2) Tuaregs,[96] (3) Anṣār al Dīne, and (4) other Islamic jihadist movements. The militant wing of CNRDR launched a coup d'état in response to the Malian government's lack of support to the Malian Army's fight against the Tuareg rebellion in Northern Mali.[97] Initially, the coup d'état presented an opportunity for the Tuaregs and Anṣār al Dīne to exploit the isolated situation in Bamako, Mali by seizing decisive control of Northern Mali. Subsequently, violent extremist organizations (VEO) recognized an opportunity to further exacerbate the Northern Mali conflict and achieve governance under Sharia law.

From January to mid-March 2012, the Malian Army faced resourcing and security challenges as they dealt with the Tuaregs and VEO support zones across the Trans Sahara (e.g., weapons smuggling and fighter transient lines from Libya). Yet, the DOS purported that Mali had a stable democratic government and significantly reduced poverty and improved the quality of life for many Malians.[98] Under this premise, the DOS severely restricted AFRICOM's training and operations in Northern Mali. To no avail, U.S. Special Operations Forces advisors to the Malian Army painted a dire operational environment in Northern Mali, through daily situation reports.[99] Even during the coup d'état, the DOS and AFRICOM were at odds of providing net assessments to decision makers. Following the coup d'état, the DOS put their investments in Economic Community of West African States (ECOWAS) to establish a regional security apparatus to defeat VEOs in Northern Mali. Ultimately, AFRICOM and the DOS did not use a collaborative strategy to deal with the spillage of the Near Eastern problem set in Libya (i.e., the Tuaregs' ties to the late Muammar al-Qaddafi).

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96 The Tuareg identity is a Berber/Muslim worldview, with a nomadic pastoralist lifestyle. The Tuaregs are an indigenous society stretching across the Trans Sahara desert region.

97 Arieff, *Crisis in Mali*, 4–5.

98 U.S. Department of State, "Situation in Mali," U.S. Department of State, accessed May 10, 2014, http://www.state.gov/r/pa/prs/ps/2012/03/186633.htm.

99 Joint Special Operations Task Force—Trans Sahara, "Daily Commander's Update Brief: Mali Crisis Action Planning" Joint Special Operations Task Force—Trans Sahara, Moeringhen, Stuttgart, Germany, 2012).

C. WICKED PROBLEM CHARACTERISTICS

Rittel and Webber contended that wicked problem embodies 10 distinct characteristics (see Table 11).[100] Decision analysts must objectively assess whether the problem meets the majority, if not all, of the characteristics. In the Case of Northern Mali, the author conducted a macro analysis of the PMESII-PT domains to appraise the 10 characteristics and determine whether the conflict was in wicked problem territory. The aforementioned activity map in Figure 12 served to illustrate the high level of multifaceted interactions between the eight PMESII-PT domains, 17 major stakeholders, macro problems and associated solutions from "etic and emic"[101] perspectives.

Table 11. Characteristics of Wicked Problem Territory[102]

Wicked Problem Characteristics	
Formulation	Not Definitive
Stopping Rules	"Better" to "worse" solutions
Test for correctness	Cascading consequences over an extended period of time
Solution Type	Good/Bad/Better/Worse/Good Enough
Trial and Error	Solution attempt has irreversible effects
Exhaustible set of solutions	No well-described set of permissible operation(s)
Unique	There are no problem "classes"
Symptom or Problem	There is no natural level.
Discrepancy	Multiple explanations
Right to be wrong	Wrong answers have consequences

In terms of the formulation attribute, the conflict in Northern Mali does not have a definitive problem statement. Rittel and Webber aptly asserted that defining the problem is commensurate with finding solutions; however, the decision analyst cannot define or understand the context of the problem statement without finding the solution(s) at the outset.[103] Although the activity map does not pinpoint a precise solution set, "an image of the problem and of the solution emerges gradually among the [stakeholders], as a product

[100] Rittel and Webber, *Dilemmas in a General Theory of Planning*, 155–169.

[101] The terms emic and etic refer to two types of viewpoints of human behavior. The emic view considers how indigenous populations think. This internal or localized point of view (i.e., impartial) is how indigenous populations perceive the world, categorize others, behave, and rationalize things. The etic view is a more scientific approach (i.e., objective) using external observations, rather than internal or local observations.

[102] Ibid.

[103] Ibid., 161.

of incessant judgment, subjected to critical argument." [104] By using the PMESII-PT domains and considering more than numerous stakeholders in the conflict, the information required to comprehend the dynamic problem led to numerous ideas to deal with the conflict (see Table 13). With too many conceptions and solutions, analysts will never truly know when they have found the "right" solution. In other words, the Northern Mali conflict has no "stopping rule," due to the various stakeholders in the epoch of diffused power (i.e., non-state actors influencing and operating in the ungoverned political spaces of the Trans Sahara region). In dealing with Stakeholder Group A (see Table 12), the immeasurable solutions range from worse to good; therefore, without a true appraisal or enumeration of solutions, decision makers may settle on a solution type that is "good enough." Thus far, Northern Mali is in wicked problem territory, because the cascading effects of influencing the problem set over time prevents analysts from testing solutions for accuracy. Even worse, there are no "do-overs," since solutions have irrevocable effects. Rittel and Webber contended that every solution to a wicked problem is a "one-shot operation," because analysts have no right or opportunity to learn by trial and error.[105] Every solution that decision makers endorse for execution counts and has waves of effects that may induce another unique wicked problem. Therefore, analysts are accountable for the consequences of the solutions they espouse.

[104] Ibid.

[105] Ibid., 163.

Table 12. Northern Mali Conflict: Stakeholders Groups A, B, and C

Stakeholder Group A	Stakeholder Group B	Stakeholder Group C
1. Rebel groups of nomadic Tuaregs and 2. Passive Tuareg Tribes 3. National Committee for the Restoration of Democracy and State (CNRDR) 4. Tuareg separatist-led National Movement for the Liberation of Azawad (MNLA) 5. High Council for the Unity of the Azawad (HCUA)	1. Economic Community of West African States (ECOWAS) 2. France 3. United States 4. African Union (AU) 5. Mali's Transitional government of National Unity 6. Loyalist Tuareg	1. Al-Qaeda in the Islamic Maghreb (AQIM) 2. Al-Mua'qi'oon Biddam 3. Ansar al Dine 4. Radical Islamist forces (e.g., Movement for Unity and Jihad in West Africa (MUJAO) and Islamic Movement of Azawad (MIA))

D. USING PMESII–PT

Previously, the activity map in Figure 12 illustrated 11 solutions and 12 problems, which are neither exhaustive nor conclusive (also see Table 13). Each of these solutions and problems can potentially multiply into other unique sets of solutions and problems, due to interdependencies among stakeholders and complexities surrounding the PMESII-PT domains. For example, one political solution is to reach a preliminary agreement following Mali's 2013 presidential election and continue inclusive peace talks with the Tuareg groups, MNLA, and HCUA. These agreements would undertake a redeployment of the coalition forces throughout Northern Mali. Clearly, this solution does not even consider half of the major stakeholders involved in the conflict or the residual problems. In another example, a military solution might be for the Western coalition in partnership with African regional security apparatuses to impose a military intervention in the form of counterterrorism, counter insurgency, or direct action operations. Likewise, this scenario (1) minimizes African players in Stakeholder Group B while creating a façade of multinational operations; (2) neglects critical players in Stakeholder Group A (e.g., passive Tuareg Tribal Leaders); and (3) shuns players in Stakeholder Group C (e.g., political leaders of MUJAO and MIA).

Table 13. Using PMESII-PT to Identify Solutions and Problems

Solutions		Problems	
P^{s1}	Redeployment of Western /AU forces	P^{p1}	Controlling political space
P^{s2}	Autonomous / semi-autonomous region	P^{p2}	Autonomous / semi-autonomous region
M^{s1}	Western/AU coalition COIN, CT, etc	M^{p1}	Securing Mali from VEOs
M^{s2}	Western/AU coalition PH.0	M^{p2}	Internal security from rebels
E^{s1}	Increase defense spending West/Africa	M^{p3}	Future coup
S^{s1}	Muslims handle it	E^{p1}	Lack of defense spending to secure
II^{s1}	Exploit Rifts	S^{p1}	Humanitarian impact
II^{s2}	Malian national liberation struggle	S^{p2}	A Muslim internal problem
I^{s1}	Exploit Rifts	II^{p1}	Indirect PT1, PS1
P^{s1}	Indirect to MS1, MS2, SS1, PS1	I^{p1}	Indirect PP2, PT1, PE1
T^{s1}	Indirect to MS2	PE^{p1}	Indir PP1, PP2, PM1, PE1, PS1, PT1
		T^{p1}	Al Suri Model

LEGEND

P^{s1}	Political Solution #1	P^{s1}	Political Problem #1
M^{s1}	Military Solution #1	M^{s1}	Military Problem #1
E^{s1}	Economic Solution #1	E^{s1}	Economic Problem #1
S^{s1}	Social Solution #1	S^{s1}	Social Problem #1
II^{s1}	Information Solution #1	II^{s1}	Information Problem #1
I^{s1}	Infrastructure Solution #1	I^{s1}	Infrastructure Problem #1
P^{s1}	Physical Environment Solution #1	P^{s1}	Physical Environment Problem #1
T^{s1}	Time Solution #1	T^{s1}	Time Problem #1

E. A COLLABORATIVE STRATEGY FOR NORTHERN MALI

As identified by the proposed solutions in the activity map and the PMESII-PT summary table, a collaborative strategy could potentially bring more players to the negotiation table. By building coalitions, the stakeholder groups might find better solutions that address critical problems in Northern Mali, while reducing negative externalities imposed on one another. Rather than a zero-sum game, coalitions would then face a partial sum game where players agree to maximize their strategic position or remain at status quo. The idea is to get stakeholder groups to shift from a competitive strategy to a collaborative strategy to maximize their payoffs, which would not otherwise occur without collaboration. Moreover, the finer points of collaboration could identify the social aspect of players in Stakeholder Group B reframing the sacred values of key players in Stakeholder Groups A and C. Through a collaborative strategy, players can maximize their payoffs and tackle what the coalition deems as the crux of the problem with acceptable risk factors, of which the coalition has already given concurrence. At the same time, however, the cost of including more players in the collaborative strategy can be detrimental. The coalition might face individual players' opportunity costs that create barriers and delay negotiations. Players may perceive that a particular solution eliminates optimal alternatives. Ultimately, the situation in Northern Mali is so dynamic that arriving at a consensus might prove too difficult for players to support a collective solution, among numerous mutually exclusive options, given inadequate resources and imperfect information.

By applying Rittel and Webber's process of determining wicked problem territory, decision analysts can tell a story grounded in morality and social context, which leads to a feasible development of the problem space unachievable by conventional approaches. However, with the intricate interdependencies of numerous stakeholders and differing worldviews, tackling wicked problems seems impossible at times in this age of design. Therefore, analysts must remain forthright as they purport to tame, cope, or tackle a wicked problem. In a complex, multi-polar environment where power and social media continue to empower individuals, analysts must carefully and responsibly making promises within the realm of possibility while including the entire system of stakeholders at the negotiation table.

F. TELLING THE STORY: A SYSTEMS APPROACH

Decision analysts must overcome conceptual roadblocks if they are to become more sophisticated thinkers and creative problem solvers. At the same time, leaders and facilitators must create conditions to allow analysts to overcome the conceptual blocks that obscure viable strategies to tackle wicked problems. In the end, however, it is incumbent upon analysts to effectively change the actual functioning of their thinking. As analysts assess their design structure, they must be introspective and wary of forming constructions of knowledge and mental process to diminish intellectual risk. Adams suggested that these structures are usually ones that have been tested, found to be successful in the past, and give us precision as we perform repetitive tasks.[106] Therefore, as decision makers advocate a culture that relies on structures and models, analysts must recognize the constraints as they process information—especially in wicked problem territory. In the end, the author identifies personal conceptual blocks, which inhibit his framing, conceptualizing, and tackling of the ungoverned spaces of the Trans Sahara.

[106] James L. Adams, *Conceptual Blockbusting: A Guide to Better Ideas* (New York: Basic Books, 1974), 22.

The case of Northern Mali provokes a wide range of solutions and problem statements amongst stakeholders. Despite a protracted impasse, decision analysts should be wary of advocating a taming strategy. Instead analysts should ethically and morally deal with the social context of the problem, rather than simplifying the problem to make it more manageable and solvable.[107] Specifically, analysts should resort to coping strategies to tackle the wicked problem (e.g., authoritative, competitive, or collaborative). By determining the diffusion of power amidst stakeholders, the optimal coping strategy becomes clearer. In other words, analysts should determine if power is concentrated or contested to choose an authoritative, competitive, or collaborative strategy.[108] At first glance, analysts might determine that power is contested and requires a competitive strategy; however, with further consideration of the waves of effects across the eight PMESII-PT domains and the associated solutions and problems, it may be more beneficial to use a collaborative strategy.

As tumultuous relations between Western state-actors and fragile African states continue to grow, violent extremist organizations (VEOs) find solace in the ungoverned spaces of the Trans Sahara. In Northern Mali, al-Qaida has built coalitions with an indigenous nomadic tribe known as the Tuaregs to promulgate its brand and cause. To counteract al-Qaida's influence in the region, the Malian central government (backed by Western state-actors) has attempted to execute various sustainable development policies aimed at eliminating violence, famine, and various economic disparities. Inadvertently, however, the Malian government continues exhibit a common pattern of recognizing a symptom and trying to fix it, only to find out that the "fix" caused another set of problems. To frame the problem effectively, design thinkers must unveil the underlying systemic structures by illustrating both behaviors and causal factors influencing the lack of sustainable development in the Trans Sahara. Anderson and Johnson suggested a systems thinking approach to layout the anatomy of problems with behavior over time

[107] Conklin, *Wicked Problems & Social Complexity*, 11.

[108] Nancy Roberts, "Coping with Wicked Problems: The Case of Afghanistan," *Research in Public Policy Analysis and Management* 11 (2001): 353–375, 357.

(BOT) diagrams and causal loop diagrams (CLD).[109] As opposed to traditional analysis, the systems approach embodies the study of variables interacting with other constituents in a system to produce some behavior. With the BOT and CLD processes, decision analysts can offer salient recommendations to decision makers while formulating the problem, identifying the key variables, graphing the behavior of variables over time, and identifying the systemic structure.

G. FORMULATING THE CORE PROBLEM

The circumstances surrounding the ungoverned region of the Trans Sahara have persisted since ancient and medieval times. The Trans Sahara represents an intermediary region of desert lands spanning across Africa (i.e., stretching from the western states of Senegal and Mauritania through Algeria, Mali, Niger, Chad, Nigeria, and on toward the coastal states in the horn of Africa). This ungoverned region is as austere as it is unforgiving. What is more, the indigenous population consists of nomadic tribes (e.g., the Tuareg tribes) that have spawned amidst the empires that have conquered Africa throughout time. As the life blood of North Africa, the significance of the Trans Sahara stems from the well-established trade routes that channeled products, treasures, slaves, systems of transhumance, and other goods and services from West Africa to the Mediterranean, Western Europe, the Horn of Africa, and the Middle East.

With the looming challenges of globalization and conflicts of 21st Century, the Saharan trade routes that facilitated the development of African cities are now being exploited by VEOs. With the help of unshakable nomadic tribes (i.e., Tuaregs) who have survived the harsh Saharan environment (via watering holes, oases, and rudimentary logistics points), the likes of al-Qaida and its affiliates have developed a strategic support zone. Naturally, many stakeholders have a vested interest in influencing the stability or instability of the ungoverned spaces of the Trans Sahara.

In recent times (i.e., since the mid-1990s), one of the greatest threats to the stability of the Trans Sahara has been al-Qaida's ability to franchise and propagate its

[109] Virginia Anderson and Lauren Johnson, *Systems Thinking Basics* (Waltham, MA: Pegasus Communications, 1997).

brand. The fear of Western state-actors and the African Union is al-Qaida's small, agile, decentralized, and flattened networks of adaptable units broadening its use of the Trans Sahara to recruit, train, finance, and support its operations throughout Africa, Europe, and the Middle East. Where fragile states and weak governances exist, VEOs mutually support one another and exploit uncontested political spaces. Arguably, the cascading effects of Arab Awakening and the falls of Hosni Mubarak in Egypt and Muammar al-Qaddafi in Libya greatly influenced the instability that VEOs enjoy throughout the Trans Sahara. According to U.S., NATO, and AU stakeholders, the threats posed by VEOs present a clear and present danger.[110]

From the Tuareg perspective, colonialists stripped nomadic tribes of their livelihood and a land to call their own. In the early 1960s, the decolonization of French imperial outposts created new African states. By the 1970s, African states like Algeria prevented the Tuaregs from taxing and securing nomadic commercial routes. The Tuaregs would later endure the severe Sahel droughts and famine of the mid-1970s to the early 1990s and rebel against the defense forces of Mali and Niger. The aftermath of these events led to disenfranchised Tuareg tribes, displaced sedentary families, deprived shantytowns, and transitions to semi-nomadic lifestyles of destitution. With the Islamic awakening movements throughout North Africa (e.g., the Arab Spring)[111], falls of al-Qaddafi and Mubarak, and the recent 2010 and 2012 droughts, perhaps the Tuaregs sought a strategy to prevent another wave of perceived threats to their identity.

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110 *2013 U.S. Africa Command Posture Statement: Statement of General Carter Ham before Senate Armed Services Committee* 113th Cong (2013) (testimony of Carter Ham); NATO Defense College and Institute for Security Studies, *AU–NATO Collaboration: Implications and Prospects*, ed. Brooke A. Smith–Windsor (Rome, Italy: NATO Defense College, Research Division, 2013), 113–146.

111 To clarify the notion of Islamic awakening movements, the analyst must also take note that where there are Islamists (i.e., those who read political philosophy and espouse politics informed by religious values), there is an enormous *post-Islamist*, *post-colonialist* sentiment expressed by peoples throughout the Middle East and North Africa (MENA) that can be facilitated by not making a fetish of Islam.

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APPENDIX B. STEP I—SYSTEMS THINKING

A. A ROADMAP FOR SYSTEMS THINKING

The author presents two systems thinking tools to frame the wicked problem in Mali. First, the author uses the behavior over time (BOT) diagram to clarify the nonlinear, interrelated behavior of variables from 1990 to 2013. However, the BOT diagram is notional due to the absence of decision analysts on the ground. The second systems thinking tool is a causal loop diagram (CLD), which helps to identify possible "reinforcing" and "balancing" processes in the overall structure. Between the BOT diagram and CLD, analysts have a start point of the system's behavior and dynamics.

B. KEY VARIABLES USED TO CREATE THE SYSTEMS MODEL

Before illustrating the BOT and CLD, decision analysts must highlight the key variables affecting the ungoverned spaces of Northern Mali. To be inclusive, these variables must derive from emic and etic perspectives of every key stakeholder in the conflict. Naturally, with numerous stakeholders who have a vested interest in the Northern Mali, analysts may never articulate every possible variable. To illustrate a strategic structure of stability in the ungoverned spaces, analysts should consider the subsystems of key stakeholders in the conflict. Moreover, analysts might focus on strategic locations in Northern Mali and assess the NSAs (e.g., Tuareg tribes) as stakeholder groups facing off against the Malian government as the opposing stakeholder group. Obviously, many other key players exist and are a part of this dynamic system. By designing the system's structure around NSAs and the Malian central government, the following variables delineate the underlying issues in the Northern Mali.

1. Level of Problem Symptoms

This variable represents the government acknowledging or not acknowledging that a fix is merely alleviating a symptom or making a commitment to solve the real problem. If the government does not acknowledge that alleviating the symptom is only a short-run solution, this variable decreases. Ultimately, the government has the ability or inability to define a problem in terms of its symptoms, thereby obscuring the real cause and leading to symptomatic solutions that fail to rectify the indispensable condition.

2. Level of Fix

This variable represents the Malian government's short-run or long-run application of development policies and strategies. The government's investments, interventions, and activities are ideally aimed at sustainable development in Northern Mali to reduce violence, famine, various economic disparities, and so forth. In the case of a short-run quick-fix, the government faces unintended consequences. With a long-run fixes, the government achieves sustainable development.

3. Level of Unintended Consequences

The key unintended consequence is violence. Due to the quick-fixes applied by the Malian government, the Tuaregs revert to coping strategies to prevent further alienation, marginalization, and disenfranchisement of the Tuaregs and their identity. The coping strategies may range from migrating to neighboring African states to transitioning from a nomadic to semi-nomadic society, responding in nonviolent protest, or responding in violence. In the latter coping strategy / unintended consequences, Tuareg rebels may collude with other VEOs thereby creating another set of unintended consequences and undermining the government's ability to execute development strategies.

With these interrelated variables, decision analysts would graph their behaviors across time (see Figure 13). Analysts could go back as far as the French Equatorial of Western Africa in the late 1800s or France's decolonization efforts in the 1960s. However, analysts could responsibly assume some risk by commencing their timeline in the early 1990s and focusing their efforts in the Western Trans Sahara. By capturing the years leading up to VEOs (e.g., the Group for Call and Combat or GSPC) taking on the al-Qaida brand, analysts can still responsibly and ethically graph the behavior of the variables still playing out in the 21st Century. This time period should give analysts nearly a decade of "behaviors" leading to the emergence of al-Qaida and its influence over VEOs and African states' failing policies.

C. DEVELOP THE BOTS

Generally speaking, the failing policies are symbolic of a "fixes that fail"[112] structure, which illustrates the Malian government's inadequate management of sustainable development. The government's development strategy seemingly has a beneficial effect, even though the long-term trend continues to depreciate. Similarly, there is an accrual of dynamic consequences, which expends resources and time that could have been used to fix the initial problem. An illustration of the enduring drawbacks of this scenario is apparent in Figure 13. Note the behavior and interrelatedness of the problem symptom and unintended consequences variables each time the Malian government applied fixes (denoted by the green triangles) that had unintended consequences and failed. Also, note that in one instance, the Malian government achieved nearly 10 years of relative stability and acceptable levels of government control, due to the 2006 Peace Accord and the resultant interventions that ended the Second Tuareg Rebellion from 1996–2007. See Figure 13 for an illustration of the BOT graph.

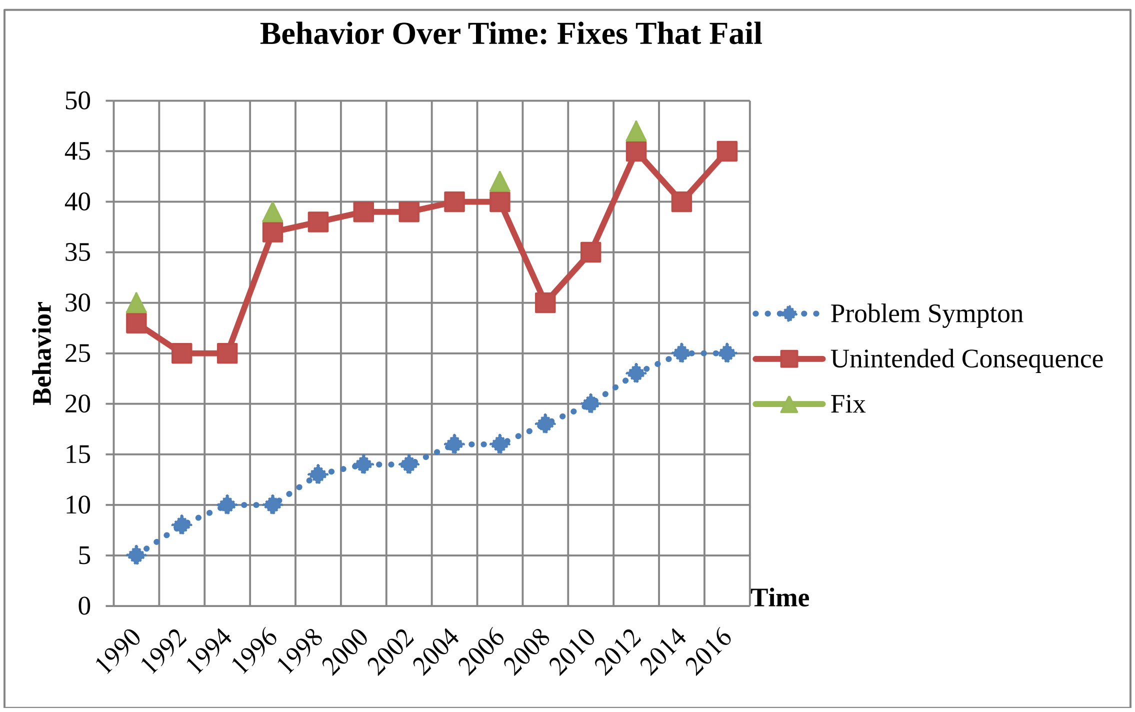

Figure 13. Behavior over Time Graph.

[112] Senge, *The Fifth Discipline*, 46–51.

D. DEVELOP THE CLD

With the help of Western state-actors, Mali launched government interventions, which were initially successful. However, the government focused much of its efforts on its city centers to maximize its shared interests with Western countries. Ultimately, the government deferred its interventions in rural areas (i.e., shanty towns and key locations in the Trans Sahara), which support the livelihood of semi-nomadic and nomadic NSAs (i.e., Tuareg tribes). The impact of needed interventions had a negative development, which led to a perceived disenfranchisement and marginalization of the NSAs. Consequently, the NSAs' compliance with the government dramatically declined over the last 23 years, and the government continually depressed its nation building capacities. See the CLD illustrated in Figure 14.

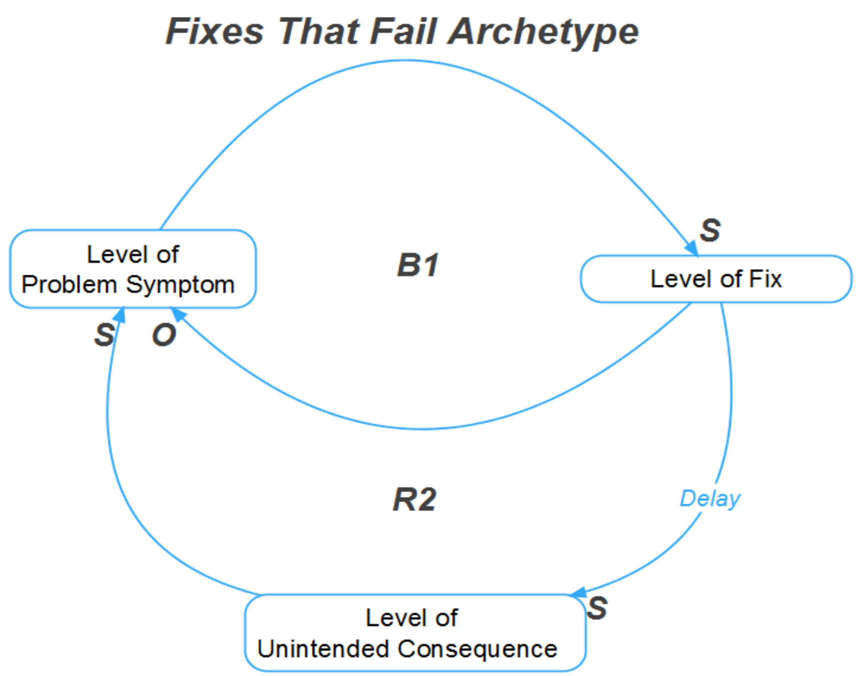

Figure 14. Causal Loop Diagram.[113]

[113] Ibid.

E. DEEP STRUCTURE SYNTHESIS

As the Malian government deals with what may seem like an inexplicably "fixes that fail" structure, it continues to apply short-range fixes with unintended consequences that exacerbate the problem. The CLD illustrates the notion that the problem symptom will diminish for a short time and subsequently revert to its previous state or degrade over time. Most likely, Malian policymakers are astounded at the problem, which they already fixed, taking on a life of its own and becoming worse than it was at the outset. This structure highlights the risks associated with "taming a problem"[114] or oversimplifying the problem. Despite the good intentions of sustainable development, Malian policymakers repeatedly deal with unchanged problem symptoms, albeit in varying shades of gray. The underlying structure reveals the residual effects of policymakers assuming that problem symptoms are inimitable sets of conditions that exist in their own isolated subsystems, which are independent of other problem symptoms or portions of the larger system. Unfortunately, reductionalist thinking permits policymakers to rationally focus on the problem symptom as a reasonable and effective response.

According to the CLD, the Malian policymakers' response primarily targets the problem symptom, rather than devoting energy and time on identifying the underlying, systemic problem. The "unintended consequences" variable, which materializes from the short-range fix, functions as a reinforcing loop (or R2) and further exacerbates the original problem symptom. Ultimately, R2 contains a delay and contributes to a progressively deteriorating problem symptom, due to the short-range fix. Although the CLD points toward appreciating or improving the "fixes that fail" structure, by targeting the delay in the balancing loop, policymakers should still exercise caution as they intervene. As time lapses between the fix and the deteriorating problem symptoms, policymakers will find it quite difficult to identify the relationship between the fix and the worsening problem symptoms. According to the CLD, Malian policymakers likely have a tendency to attribute the degenerating problem symptom to other contributors, rather than finding culpability in their efforts to fix the problem symptoms. Notwithstanding its

[114] Roberts, *Coping with Wicked Problems: The Case of Afghanistan*, 368–369.

outwardly simplistic structure, the “fixes that fail” structure is a problem that is wicked and tough to tackle. To improve this structure, policymakers must cast aside reductionalistic models, which preclude the recognition of the links between the “visible” problem symptoms and the fixes policymakers apply to alleviate the problem symptoms.

F. CONCLUSIONS FROM THE BOTS AND CLD

Since the BOT diagrams and CLD only serve as a start point, decision analysts would need to collect data to simulate and verify the system’s structure and make necessary modifications for further analysis. Although qualitative and quantitative results may facilitate a timely decision-making process (via CLD simulation), analysts would still need to constantly reassess the dynamic structure, look for repeating patterns of quick fixes, determine how often these fixes occurred, and compare their findings against the frequency with which the Malian government characteristically appraises its performance. Ultimately, sponsors, conveners, and design teams must remain vigilant of conceptual blocks that make us “prisoners of the system or prisoners of our own thinking.”[115] If analysts were recommending strategies to stabilize the Northern Mali, they would likely face the quandary of advising leaders about the significance of time delays that affect the level of unintended consequences. This dilemma compounds if leaders do not take action in a timely manner, because the opportunities and threats that presented themselves may change drastically over time.

[115] Senge, *The Fifth Discipline*, 58–67.

APPENDIX C. STEP II—DESIGN THINKING

A. STEP II—IDENTIFY: DESIGN THINKING

Over the last decade, the Malian government has launched contradictory government interventions, which were initially successful; however, it focused on short-run remedies that would eventually fail. Even worse, these quick fixes targeted the problem symptoms inherent to the austere ungoverned spaces of the Trans Sahara. From the perspective of violent non–state-actors (NSAs), the Malian government applied end-run interventions (i.e., fixes that bypassed the barriers that are fundamental to the original problem), while politically targeting its loyal constituencies in key city centers to maximize its national interests. These quick fixes led to violent NSAs perceiving a feeling of disenfranchisement and marginalization. As a result, violent NSAs continue to disregard the government and destabilize the region, while the Malian government continually applies "fixes that fail," which only served to depress its nation building capacities.

First, the author defines key interrelated variables to segue into the major causal factors in the problem. Next, the author presents two projects that decision analysts might apply at an intervention point (i.e., the unintended consequences) in the wicked problem. Provided that the two projects are long-term investments, the author explores the notion that the government can propose a "new idea" that is widely accepted and serves as the cornerstone of sustainable development. Finally, the author prototypes the new idea in an effort to sway others to accept and commit to the intervention.

B. TACKLING WICKED PROBLEMS WITH DESIGN THINKING

From one perspective, the Malian government entered wicked problem territory, when violent NSAs began destabilizing the Trans Sahara in a collaborative effort. Perhaps a "perfect storm" occurred when the Tuaregs pursued coping strategies by rebelling against the government to save their Tuareg identity, Berber/Muslim worldview, and nomadic lifestyle, while al–Qaida was promulgating its brand and vision of Islam. Although the government recognizes that a problem exists, its decision makers were merely applying quick fixes that ignored the unintended consequences and exacerbated the originating problem. Unfortunately, the government focused on the problem symptoms, which had the tendency to diminish for a short period and revert to the initial problem. Instead, the government should have applied long-term, sustainable-development projects (i.e., political, economic, social, and military interventions that reduced violence, famine, various economic disparities, and so forth). With long-term fixes geared toward sustainable development, decision makers would have broken the cycle of repeatedly tackling unsolvable problem symptoms. As a result, the government would take synoptic approaches to tackle a "systems of problems."[116] By encouraging design teams to devote their maximum energy and time on the causal, systemic problems, conveners and decision makers can finally develop guidance, policies, and strategies that ably tackle the "unintended consequence" variable. Thus, the interventions of sustainable development have the potential to materialize and address the original problem.

C. IDENTIFY AN INTERVENTION POINT

Rather than espousing oversimplifying modeling assumptions with claims of "ceteris paribus," Malian policymakers and decision makers must tackle reality of the wicked problem head on. Making this responsible mental leap allows the government to intervene only when long-term "fixes" do more good than harm and embody the most manageable consequences. Although quick fixes seemingly extend decision makers' timeline to eventually solve the root problem, short-term and long-term interventions are diametrically opposed. Therefore, to avoid the vicious cycle of solving problem symptoms of yesterday, analysts should tackle the wicked problem along two approaches:

D. IDENTIFY THE INTERVENTION

Decision analysts can significantly intervene in the causal loop diagram at the unintended consequences variable through TSI 2.0 sustainable-development projects, which consist of land rehabilitation and integrated, indigenous security forces.

[116] Ackoff, *Redesigning the Future.*

1. The Reversal of Desertification

For decades, the Sahel has been a hostile and austere region that separates the economies of the Mediterranean and the Niger basin. Perhaps African nations would revitalize the Sahel, if the expected benefits outweighed the costs. Although the Sahara has always been the lifeblood of Africa, the cascading effects of desertification have prevented African nations from taking serious action against this dynamic phenomenon. Desertification is a vicious blend of interrelated climatological and manmade variables that degrade the lands of arid regions. Before the southern encroachment of desertification into Mali's city centers (e.g., Timbuktu), the Tuaregs relatively prospered and maintained a degree of agricultural and livestock. In fact, along the southern border of the Trans Sahara, the Tuaregs once thrived in the vast trading empires of the Sahel region, despite intermittent droughts and famine. However, as desertification amplified, the Trans Sahara's ecological zone grew more fragile and less capable of sustaining the rising population. Ultimately, the destructiveness of desertification, coupled with foreseeable droughts and famine, increased demands on the terrain. Therefore, decision analysts might explore forestation projects to halt the southwardly encroaching desert and regain key locations lost to the Sahel's desert (e.g., forestation of cities and networked oases and wells).

The climatic variables affecting desertification (e.g., arid conditions and droughts) are not the only factors contributing to the real problem, nor are the broad claims of nomads destroying the region by putting too much pressure on the land (e.g., overgrazing). By acknowledging the social context of the situation, decision analysts will consider internal and external factors affecting Mali's failure to tackle desertification, droughts, and famine in the Sahel. Specifically, analysts might consider the history of trans-Saharan governments interfering with the indigenous system of property rights and market interactions, followed by African governments' collectivist policies and aid from other nations, which also intensified pressure on the land.

To reverse desertification, design teams should explore the history two distinct populations of the Trans Sahara inhabiting the region: nomads and sedentary farmers. From this traditional perspective, decision analysts would find that nomads and sedentary farmers were bound together by an elaborate structure of trade markets and division of labor, which allowed them to consume existing resources without decimating the environment. For example, analysts would explore the history of Tuaregs (nomadic tribes) deriving profits from cattle (e.g., sheep and goats) and Trans Saharan trade. Central to the Tuaregs' successful trading were their strategically networked water wells, which were owned and strictly regulated by the clans that excavated them. If the government revitalized oases throughout the Trans Sahara and worked with Tuareg clans' leaders, from a private market approach, the Tuaregs would grant rights, regulate water rights, and contract networked water wells. This project would revitalize the Tuaregs network of wells to support their cattle and trade and indirectly support integrated (Tuareg–Malian) security projects along the Trans Saharan trade routes. Although the Tuaregs would privately own their cattle, the Tuareg clans would control the networked water wells and pasture lands. With limited help from the government (e.g., reforestation of strategic oases, excavating more networked wells, building salt traps, and providing limited veterinary and medical assistance), the Tuaregs would regulate the communal ownership of the pasture, mitigate overgrazing, limit usage of each well, and constrain the number of cattle that individual households own. Ultimately, with limited government help, the Tuaregs could develop a system of fully defined property rights to insulate its people from droughts, famine, and the spread of desertification.

2. Governments' Land Usage Contribution to Desertification

To promote solidarity, the government must reconsider projects like uranium mining, which contaminates and depletes crucial sources of groundwater and diminishes grazing lands. Uranium exploitation creates a lack of water and forces competition among Saharan communities for scarce resources. To reduce tensions, the government must work alongside the Tuaregs to monitor and regulate the rights of networked wells and mitigate overgrazing to relieve pressure on the land and its resources. In the same light, to prevent stagnation, the government must reassure the Tuaregs that the cattle market is reliable and incentivize them to maintain herds that the land can feasibly sustain. In time, the Tuaregs would prevent deforestation and overgrazing of collectively owned land. Just as the clans' leaders regulated well usage, they would have to regulate the depletion of forests to maintain the soil in oases projects and forestation projects in the city centers. Ultimately, to prevent the Tuaregs from "tragedy of the commons," the project must foster responsible policymaking, strengthen property rights, and promote healthy land-use practices.

3. Reversal of Desertification and Oases Experiments

Incontrovertibly, strategic arable locations are vital for the inhabitants of Northern Mali, and it is especially essential for nomadic Tuaregs. Projects aimed at reversing desertification (i.e., the swelling of arid, desert lands) in key locations could have positive effects (e.g., contribute to climate change and induce the Tuaregs compliance with central governance). As a threat to sustainable development, the menacing spread of desertification should prompt every stakeholder to collaborate. By reversing desertification, the Malian oases project could potentially alleviate other deficits (e.g., poverty, famine, and refugee migrations). However, decision makers must ensure that the interventions help the indigenous populace use the asset—strategic oases and forestation—sustainably. In effect, Northern Mali would serve as a start point to become a transnational engine for sustainable development throughout the Trans Sahara.

In the backdrop, Malian leaders must constantly measure the political will of each stakeholder affected by the intervention. First, the leaders must assess its own and its constituents' political will by determining its willingness to invest in launching the Reversal of Desertification project. Decision makers must weigh the costs, risks, and benefits of investing some percentage of its discretionary and mandatory budgets into the build-out of oases refuges, agriculture opportunities, and issues of famine and food insecurities. Ultimately, political will calls on all Malians to consider long-term, coordinated interventions that will address the country's ability to tackle climate change and espouse all aspects of biological diversity to reverse the growing desertification problem. With an effective forestation / oases project, the Malian government could work with the Tuaregs to build projects that stabilize the soil, reduce wind and water erosion, use manure as fertilizer, use terracing for landscaping, develop salt traps to retain groundwater, use irrigation improvements, regulate rotational grazing to reduce pressure on oases, and other sustainable developments.

4. The Integration of Indigenous Security Forces

Following France's decolonization of North Africa in the 1960s, the traditional Tuareg territory was transferred to several African nations of the Sahel (e.g., Mali, Algeria, Niger, and Libya). This division created competition for resources and sparked major conflicts between the African nations and the Tuaregs. Meanwhile, desertification continued to invade southwardly, while economic constraints and political issues followed African nations' independence from France. For example, Mali began to place tight restrictions on nomadization, due to population growth, which affected the Tuaregs. Implementing this policy sought to alleviate the problem symptom of desertification being exacerbated by nomadic activity; however, restricting nomadization forced the Tuaregs to abandon their life style, begin farming, and seek jobs in towns and cities. Since Mali's independence, the Tuaregs have rebelled against the new state of Mali in three to four rebellions (e.g., the Azawad and Kidal regions of Northern Mali), depending on whose historical account analysts chose to acknowledge.

Although the notion of integrating the Tuaregs into African militaries is not a new concept (e.g., the French–Algerian initiation of the 1992 peace accord[117]), the Malian government can revisit lessons learned and only pursue long-term investments that look beyond the transference of central governance and pledge of integrating Tuaregs into Mali's defense forces. For example, the Integration of Security Forces project should incorporate the development of Berberism and the Tuareg ethnic revival developed since the 1990s. Furthermore, as the government integrates the Tuaregs, it should ensure that the Tuaregs do not continue to perceive the integration as diplomatically and economically marginalizing. For example, the Tuaregs should secure the Saharan trade routes, oases / forestation projects, networked watering wells, and so forth. In doing so,

[117] Jennifer C. Seely, "A Political Analysis of Decentralisation: Coopting the Tuareg Threat in Mali," *The Journal of Modern African Studies* 39, no. 03 (2001): 499–524.

the cascading effects would not only help to reframe the government's position on the Tuaregs' identity and drive a wedge between VEOs and violent NSAs,[118] but it also restores the Tuaregs' matrilineal lines that once exalted the high status of Tuareg women (i.e., even higher than that of their Muslim and Arab counterparts). With men no longer settling as agriculturalists or semi-nomadic herdsmen, they can revitalize the Tuaregs' reliance on matriarchs as they secure jobs as nomads, soldiers, caravan leaders, and so forth.

5. The Cascading Effects of the Projects

With projects to secure Sahel trade routes, support oases build-outs, and sustain other micro-projects that reverse desertification, the Malian government could combat further degradation of the desert. By combating desertification, the Malian government can finally begin to deal with issues surrounding droughts, famine, migration, and armed crises. With buy-in from the indigenous population, the government in concert with other African nations can finally complete and improve the Trans-Saharan Highway, which has the potential to create jobs, boost the economy, and improve stability in the region. However, the key is for African nations to abstain from tempting quick fixes (e.g., excavating the Sahara for its hidden treasures, providing fiber-optic connectivity, and building pipelines for gas and oil transportation, and so forth). The Saharan projects must get buy-in from the indigenous populace and give primacy to the social welfare of the indigenous population before pursuing alternate agendas. Otherwise, the mutual benefits of other African nations would be for naught. Al-Qaida and other violent NSAs would easily exploit short-run and end-run fixes with strategic messaging and spoiling terrorist attacks if necessary. Mali would have to take on heavy costs and risks as a commitment to its long-term fixes. For example, in addition to the forestation project, the government could propose a power generation project (i.e., a solar and wind energy project) that

[118] The al-Qaddafi regime championed the Tuaregs, who became reliable, regime protectors fighting against the Libyan revolution. His Tuareg entourage provided support networks throughout the remote sanctuaries of the Trans Sahara. Al-Qaddafi understood the advantages of enticing the Tuaregs, by embracing them in his pan-African movement to protect his interests. With the Trans Sahara and the Tuaregs serving as a buffer against opponents, al-Qaddafi sought to create a support infrastructure that would ensure his regime's survivability. VEOs also recognized the Tuaregs' capabilities and leveraged these strengths as well, as evidenced by the 2012 takeover of Northern Mali.

supports Saharan trading by making jobs available predominately to the indigenous populace: security forces, energy plant jobs, government jobs to manage property rights, and so forth. Ultimately, the projects must consider the full magnitude of political, social, economic, and military problems that come with the Sahel. However, the government would have to champion a convener who is a consummate environmentalist / social entrepreneur capable of managing networks of talented Africans, strategically managing the movement of goods and services, and collaborating with various African governments, industries, academia, and non-governmental organizations. The convener's vision must trickle to the decision analysts who must help to carry the African torch of prototyping the new idea of transforming Northern Mali's movement of solidarity. Additionally, the Malian government can deal with education and job creation, technological advancements, poverty alleviation, and forestation efforts. Ultimately, the Malian government would principally demonstrate the ability to seek indigenous subject matter experts to shoulder the majority of the tasks.

Figure 15 represents the first draft of a prototype prior to developing the two IP models presented in the preceding chapters. However, the project designs in Chapters VI and VII share the same logic as the preliminary prototype. Ultimately, Figure 18 represents the product that analysts would use during the COA selection and comparison process.

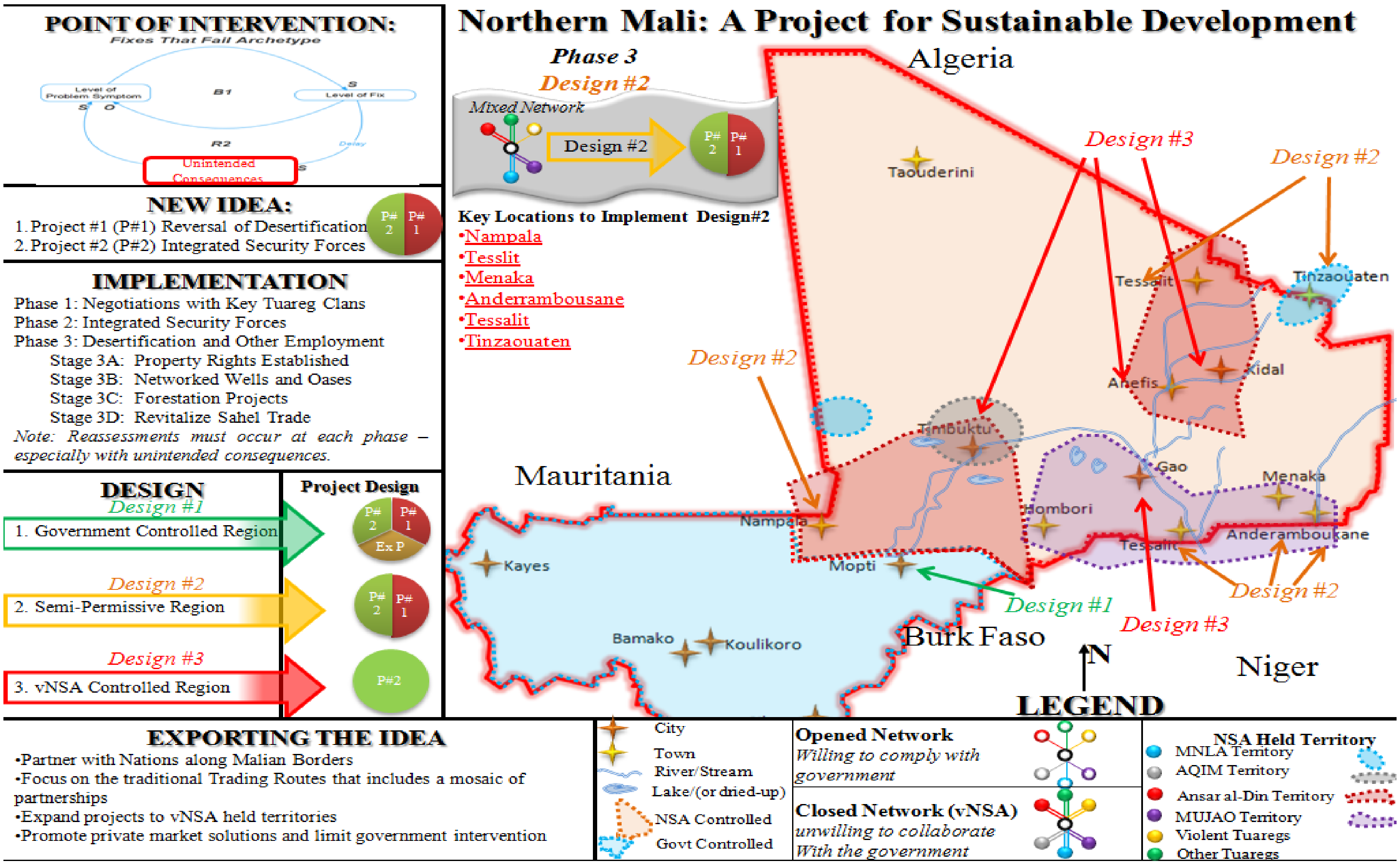

Figure 15. Implementing a Sustainable Development in Northern Mali

The roadblocks that decision analysts may encounter with applying interventions are denoted by the “opened and closed networks” of stakeholders. Each region in the Sahel has its unique set of stakeholders that present obstructions to government interventions. Therefore, analysts must establish collaborative networks to accomplish sustainable development. With each region, analysts must tailor their implementation of Projects 1 and 2.

1. Design 1 incorporates Project 1, Project 2, and exporting both projects to other critical locations in the Sahel.
2. Design 2 incorporates Project 1 and Project 2.
3. Design 3 only incorporates Project 2.
4. All three design approaches are three-phased operations from which decision analysts can tailor and blend government interventions as necessary.

6. Recommendations for Building Partner Capacity

By prototyping a project that targets the point of intervention, decision analysts can deductively get to the core of the problem. In terms of identifying a prototype, the two projects highlighted the following lessons learned:

1. Raise the Malian government’s awareness of unintended consequences
2. Reframe the root problem, and dismiss quick fixes to solve problem symptoms
3. Proactively reassess the unintended consequences, and select long-term interventions that do no harm and plan for consequence management.
4. Be highly selective and limit the frequency of applying enduring fixes.

More importantly, the design approach gave a salient perspective from which to understand and improve the intervention. By tailoring the prototype to each strategic location throughout Northern Mali (see Figure 15), decision makers have a greater chance at achieving success. In doing so, other African nations may be encouraged and motivated to employ design teams to collectively tackle the Trans Sahara’s wicked problem. Ultimately, the Malian prototype / project would serve as an example (i.e., the notion of exporting the new idea) from which other African nations can modify as they see fit. Desertification sees no boundaries, and the violent NSAs that operate in the Trans

Sahara rely on contiguous support zones and safe havens that are not bounded by state borders. Therefore, the Trans Sahara project must be networked and collaborative as well.

In the meantime, Northern Mali would serve well as a test-bed for the project. The systematic development of sustainable oases experiments, integrated security forces, and reversal of desertification, can potentially serve as a model for other African nations of the Trans Sahara. In time, other African nations would have the metrics decision makers need to derive cost–benefit decision analyses and launch evidence-based projects. By getting at the social context of the situation, Malian policymakers lead by example and showcase how the Trans Saharan project has the potential to propagate from the Western Sahara to the far reaches of the Horn of Africa. In the intervening time, Malian envoys and diplomats can engage African leaders of other nations to bring in future stakeholders at the outset to garner mutual support and identify political and social challenges unique to each African state. After all, to achieve the notion of sustainable development, the long-term intervention must be a collective effort.

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APPENDIX D. INPUT DATA FOR SUSTAINABLE DEVELOPMENT

The sum of the following factors is equal to c_i as expressed in Chapter VI:

$\alpha_{i1} = [0,1] =$ population density

$\alpha_{i2} = [0,1] =$ existing bodies of water

$\alpha_{i3} = [0,1] =$ flood frequency

$\alpha_{i4} = [0,1] =$ drought mortality risk

$\alpha_{i5} = [0,1] =$ cropland intensity

$\alpha_{i6} = [0,1] =$ illicit routes

$\alpha_{i7} = [0,1] =$ violent NSA-controlled territory

$\alpha_{i8} = [0,1] =$ significant activities (SIGACTS)

For Model II, analysts use the following criteria for c'_i :

$\alpha'_{i1} = [0,1] =$ population density

$\alpha'_{i2} = [0,1] =$ existing bodies of water

$\alpha'_{i3} = [0,1] =$ flood frequency

$\alpha'_{i4} = [0,1] =$ drought mortality risk

$\alpha'_{i5} = [0,1] =$ cropland intensity

$\alpha'_{i6} = [0,1] =$ illicit routes

$\alpha'_{i7} = [0,1] =$ violent NSA-controlled territory

$\alpha'_{i8} = [0,1] =$ significant activities (SIGACTS)

A. FACTOR 1, DEVELOPMENT: POPULATION DENSITY

Northern Mali is a highly diverse region of the Trans Sahara. Unlike the southern region of Mali, where most of the government focuses its economic and development activities, the population of Northern Mali lives in poverty and austere desert conditions. Sustainable agriculture activities must expand to Northern Mali to improve development, employment, free trade, the gross domestic product, and more.

Figures 16 and 17 are screenshots of City Population and the World Bank Group's web-based tools. The data for α_{i1} are derived by zooming into each region and reading the population densities for each of the 47 communes.

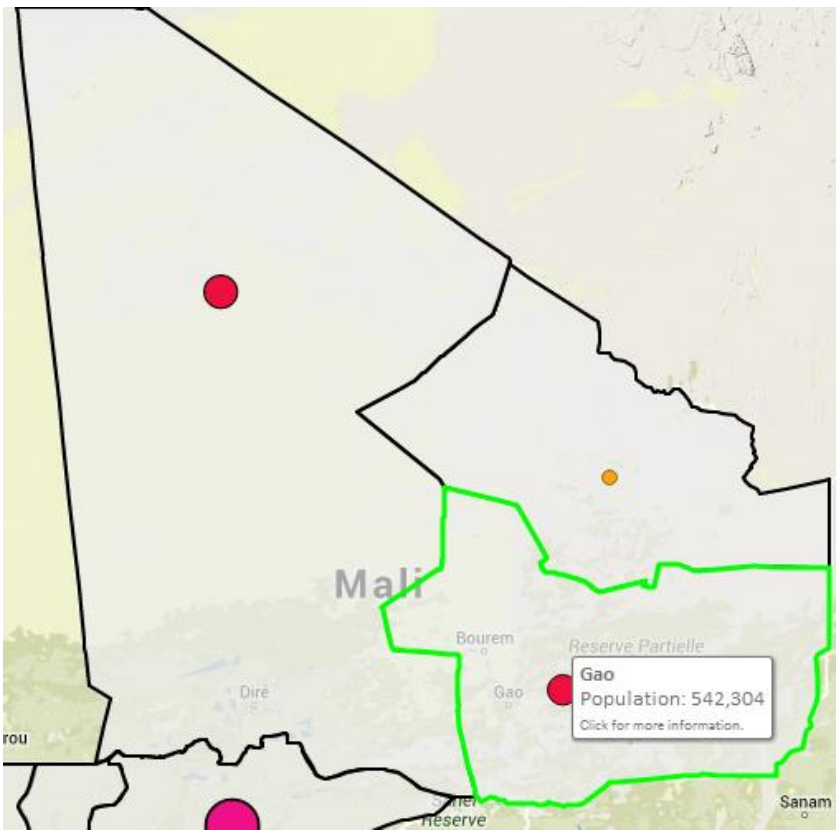

Figure 16. Factor 1: Population (Gao, Kidal, and Tombouctou)[119]

[119] City Population, "Population Statistics for Countries."

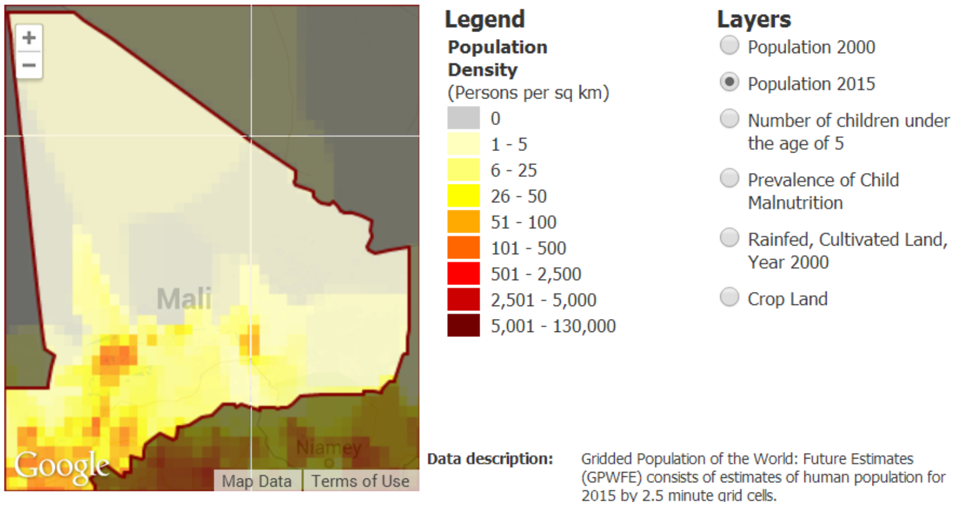

Figure 17. Factor 1: Population Density (Gao, Kidal, and Tombouctou)[120]

B. FACTOR 2, DEVELOPMENT: EXISTING BODIES OF WATER

Only 14 percent of the country's land area is considered suitable for agriculture (e.g., millet, sorghum millet, cotton, and rice), which makes sustainable land management a major concern.[121] Therefore, the "existing bodies of water" factor is essential. Figure 18 is a screenshot of The World Bank Group's web-based tools. The data are derived by zooming into each region and reading the population densities for all 47 communes.

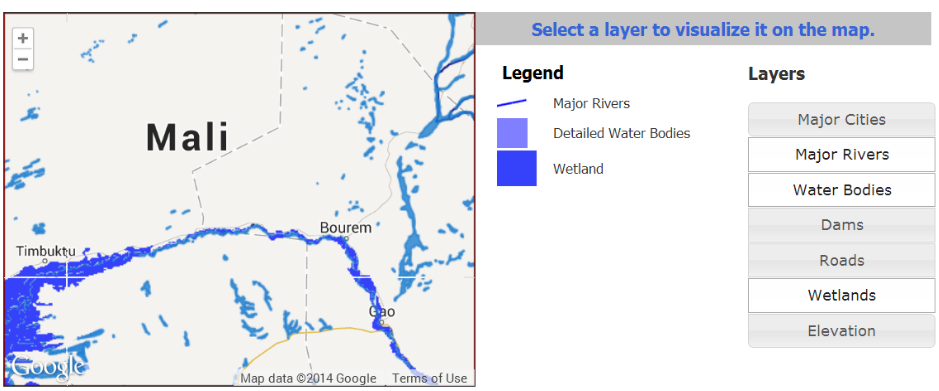

Figure 18. Factor 2: Existing Bodies of Water (Gao, Kidal, and Tombouctou)[122]

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120 The World Bank Group, *World Bank Climate Variability Tool.*

121 Ibid.

122 Ibid.

C. FACTOR 3, DEVELOPMENT: FLOOD FREQUENCY

"Flood frequency" factor assesses the expansion of agriculture, coupled with poor land management practices. On the Niger River flood plain, the region has significantly increased erosion and sedimentation, and the propensity of some areas to experience severe flooding and subsequent crop loss. [123] The average number of flood events per 100 years was based on observed flood data from 1999 to 2007.[124]

Figure 19 is a screenshot of The World Bank Group's web-based tools. The data for α_{i3} are derived by zooming into each region and determining the flood frequencies for each of the 47 communes.

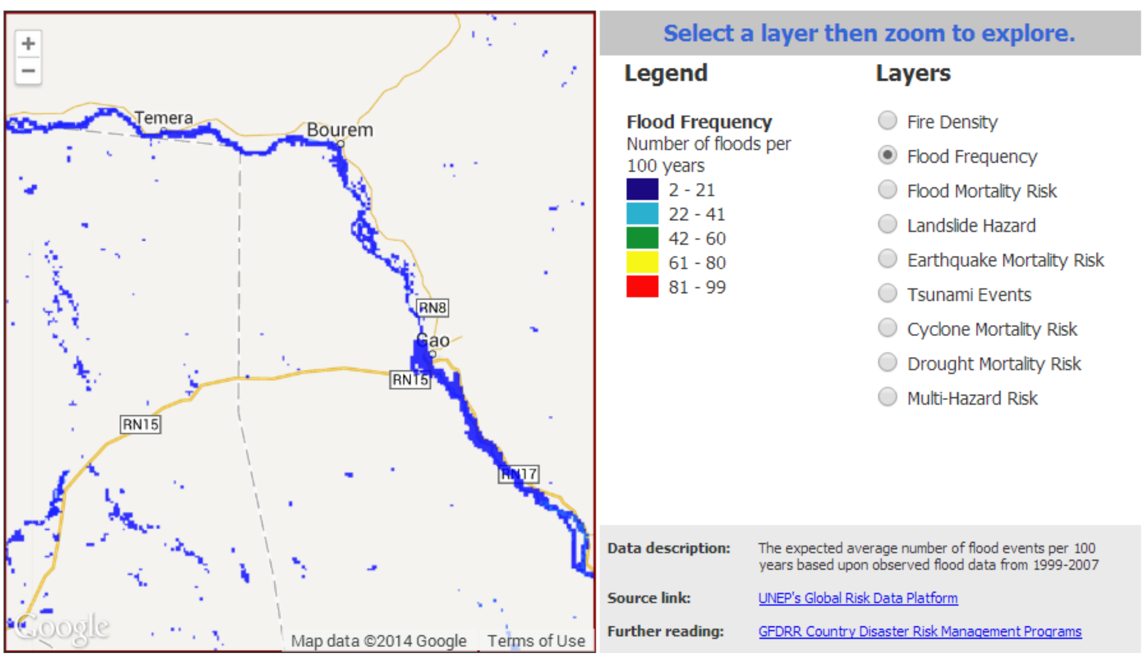

Figure 19. Factor 3: Flood Frequency (Gao and Tombouctou)[125]

[123] Ibid.

[124] Ibid.

[125] Ibid.

D. FACTOR 4, DEVELOPMENT: DROUGHT MORTALITY RISK

The "drought mortality risk" factor considers the threat on development and food security and their intensity and frequency.[126] The recent droughts forced pastoralists to remain near permanent water sources leading to considerable overgrazing. The predicted increases in temperatures, coupled with reduced or erratic rainfall are likely to continue to make natural hazards more frequent and severe. Without improved planning and management, the incidence and impacts of these disasters will increase. Figure 20 is a screenshot of The World Bank Group's web-based tools. The data for α_{i4} are derived by zooming into each region and reading the population densities for each of the 47 communes.

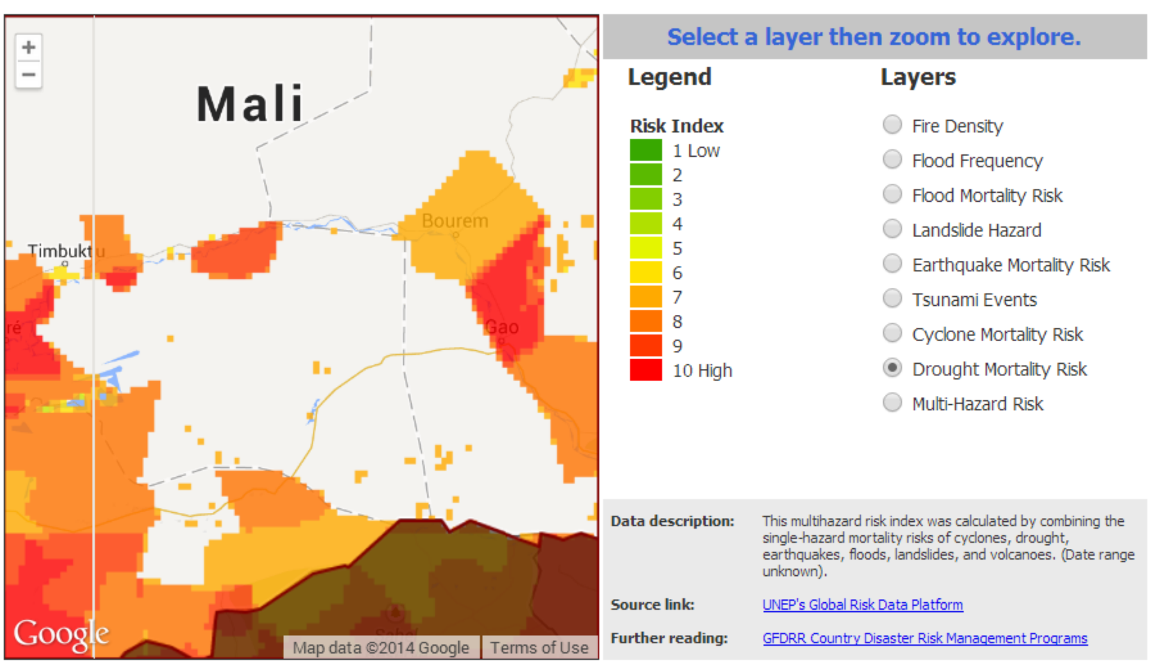

Figure 20. Factor 4: Drought Mortality Risk (Gao and Tombouctou)[127]

[126] Ibid.

[127] Ibid.

E. FACTOR 5, DEVELOPMENT: CROPLAND INTENSITY

The "cropland intensity" considers the estimated cultivated land as of 1992. Figure 21 is a screenshot of The World Bank Group's web-based tools. The data for α_{i5} are derived by zooming into each region and determining the cropland intensities for each of the 47 communes.

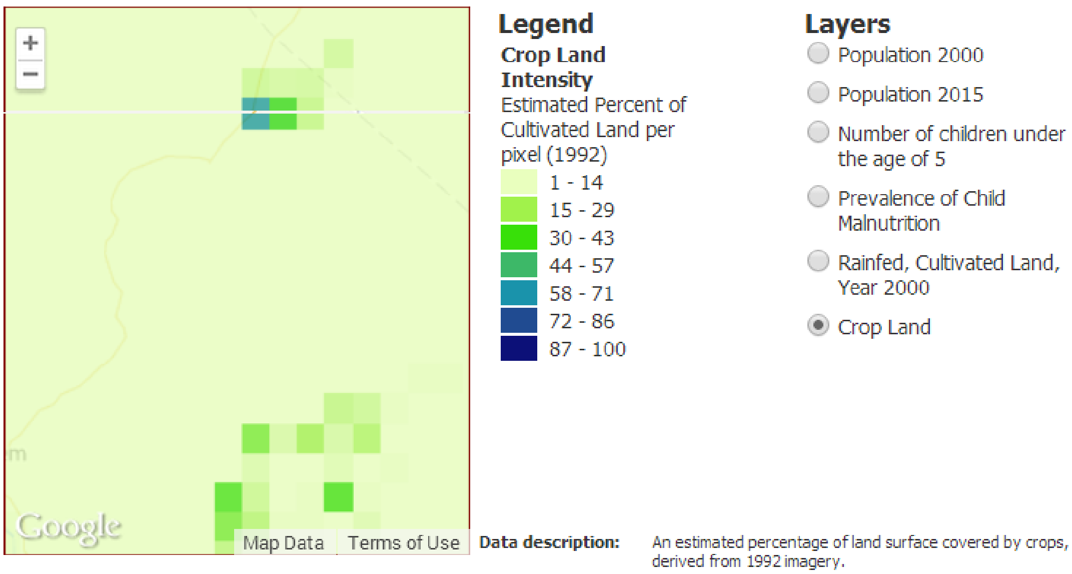

Figure 21. Factor 5: Cropland Intensity (Gao and Kidal)[128]

F. FACTOR 6, THREAT: ILLICIT ROUTES

Figure 22 is a screenshot of an unclassified threat situation map found online.

[128] Ibid.

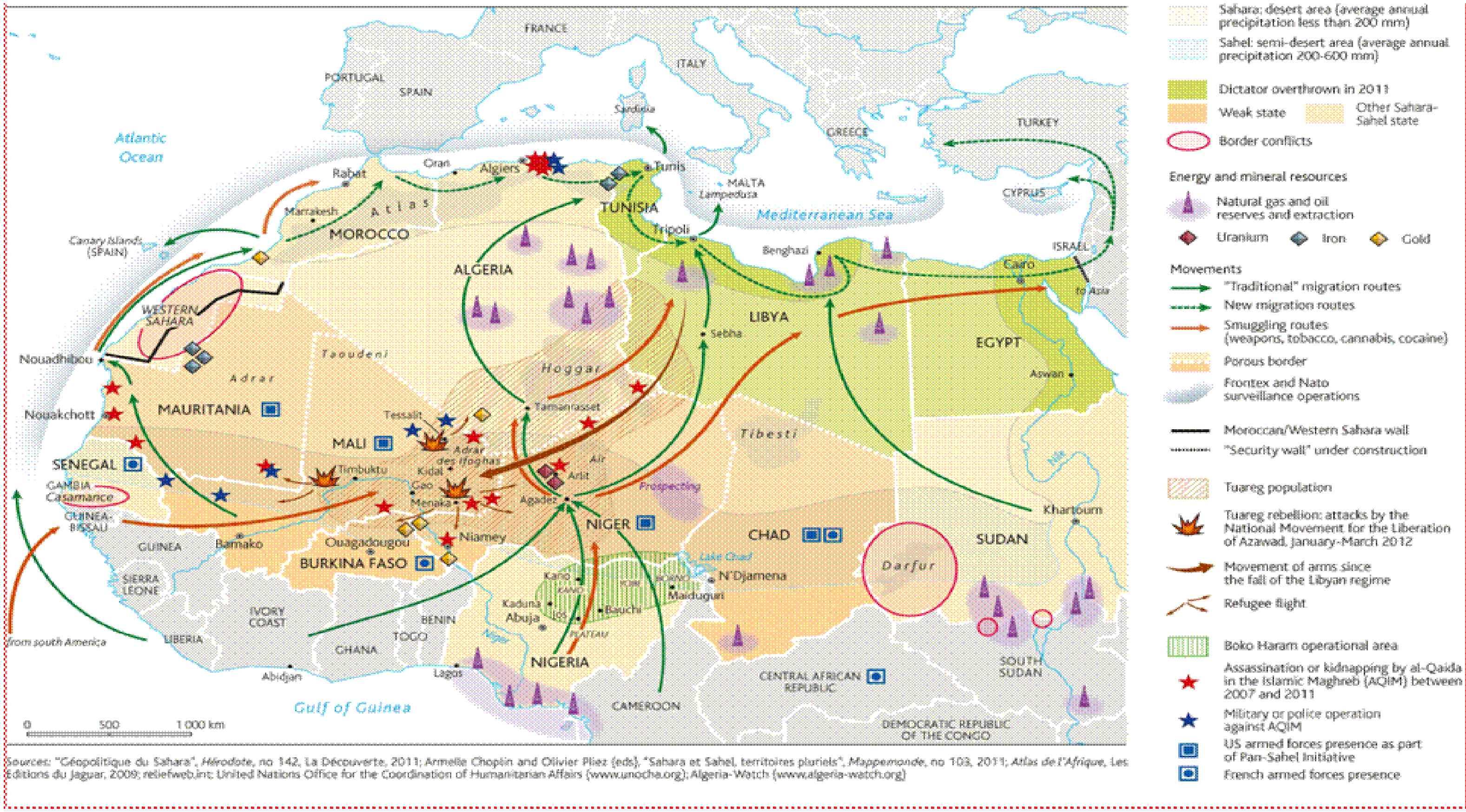

Figure 22. Factor 6: Threat Situation Template Map[129]

129 Philippe Rekacewicz, "Sahara–Sahel: Movements and Routes," Le Monde Diplomatique, http://mondediplo.com/maps/saharasahel.

G. FACTOR 7, THREAT: VIOLENT NSA / VEO CONTROL

Figures 23 and 24 are screenshots of unclassified threat situation maps found online. The data for α_{i7} are derived by zooming into each region and determining whether VEOs control any of the 47 communes.

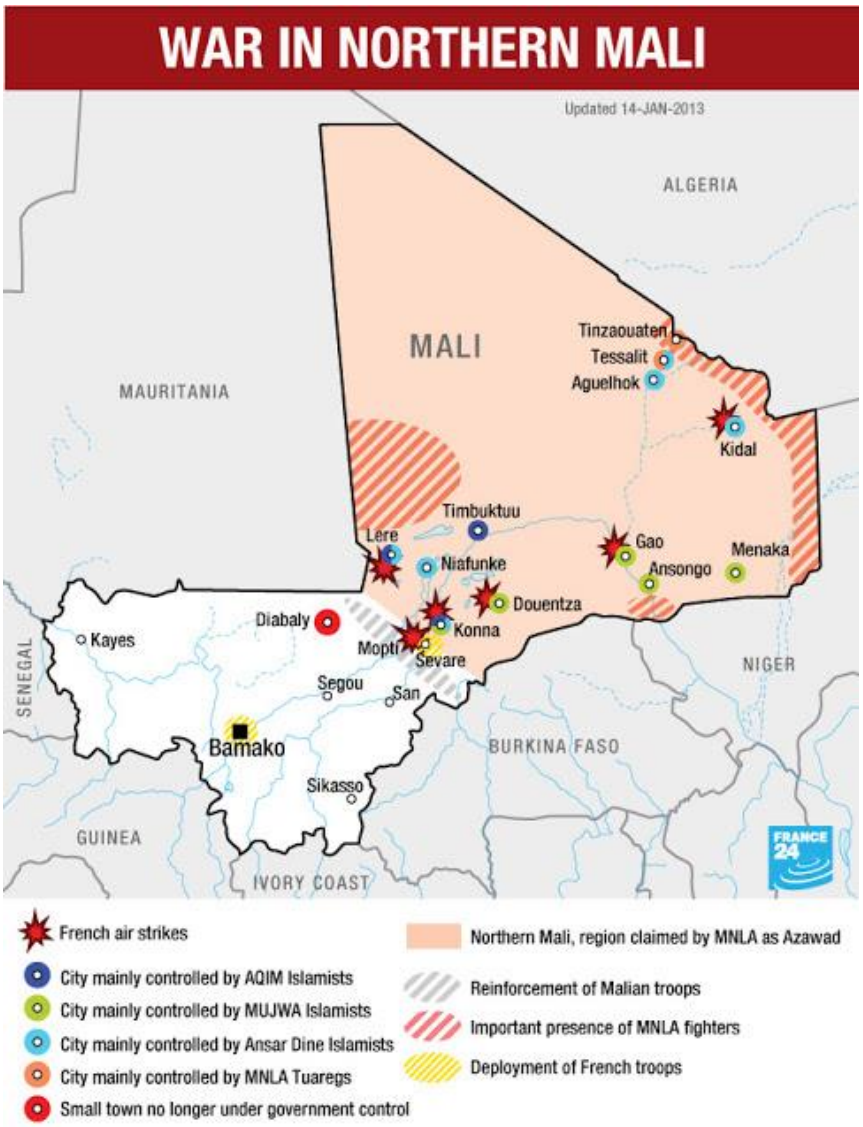

Figure 23. Factor 7: Conflict Zones in Northern Mali: VEOs and NSAs[130]

[130] France 24, *War in Northern Mali* (Les Moulineaux, France: France24, 2013), http://1389blog.com/pix/war–in–northern–mali.jpg.

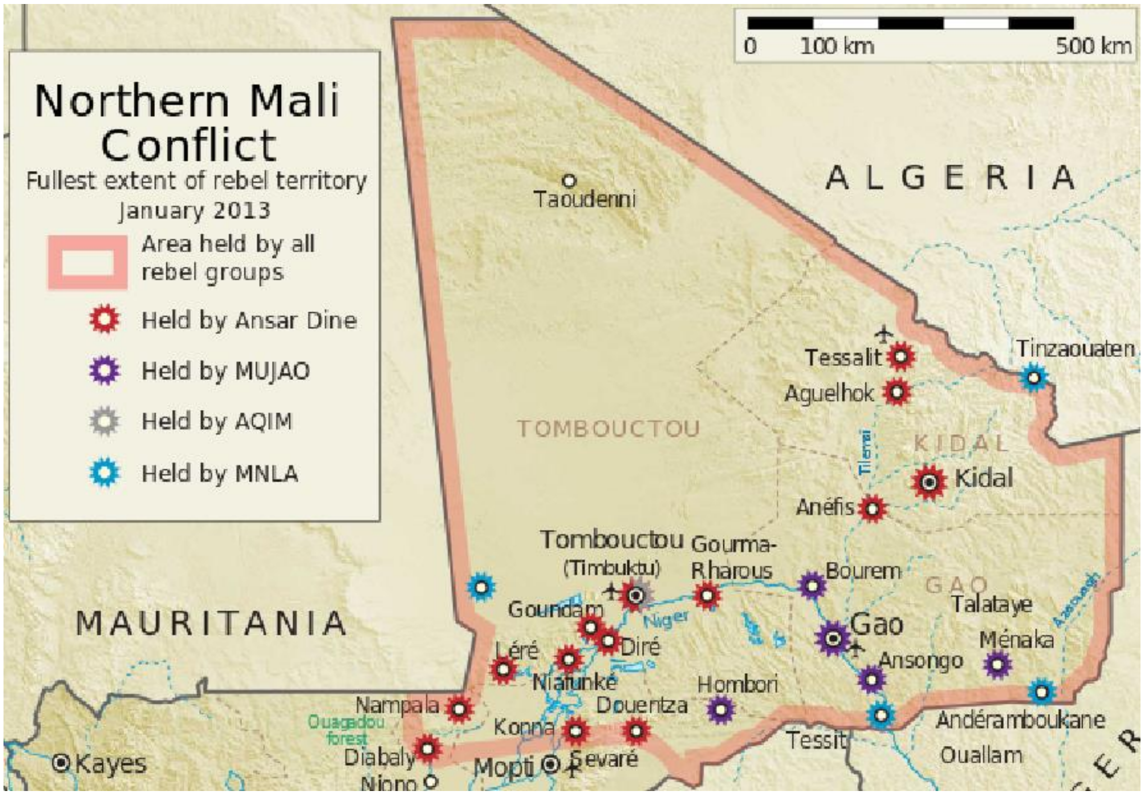

Figure 24. Factor 7: Conflict Zones in Northern Mali: VEOs and NSAs[131]

H. FACTOR 8, THREAT: SIGNIFICANT ACTIVITIES

Figures 25 and 26 are screenshots of unclassified threat situation maps found online (also refer to Figures 22, 23, and 24). The data for α_{i8} are derived by zooming into each region and accounting for significant activities (i.e., VEO operations, major fighting between coalition and VEOs, and so forth) for each of the 47 communes.

[131] William Engdahl, "Mali and AFRICOM's Africa Agenda: Target China." (January 31, 2013), http://www.voltairenet.org/article177327.html

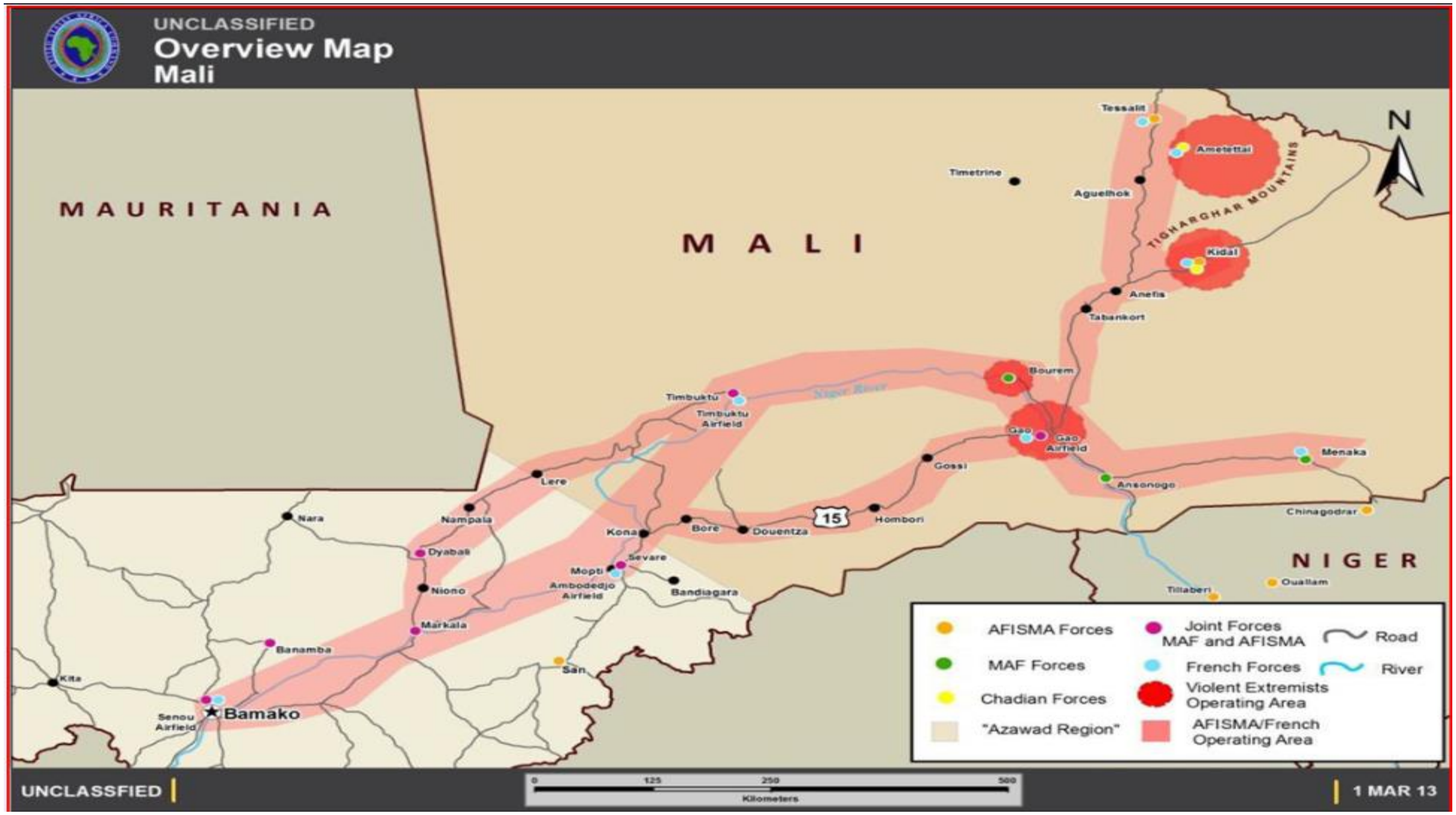

Figure 25. Factor 8: Threat Overview Map 1[132]

132 2013 U.S. Africa Command Posture Statement: Statement of General Carter Ham before Senate Armed Services Committee 113th Cong (2013) (testimony of Carter Ham), 8.

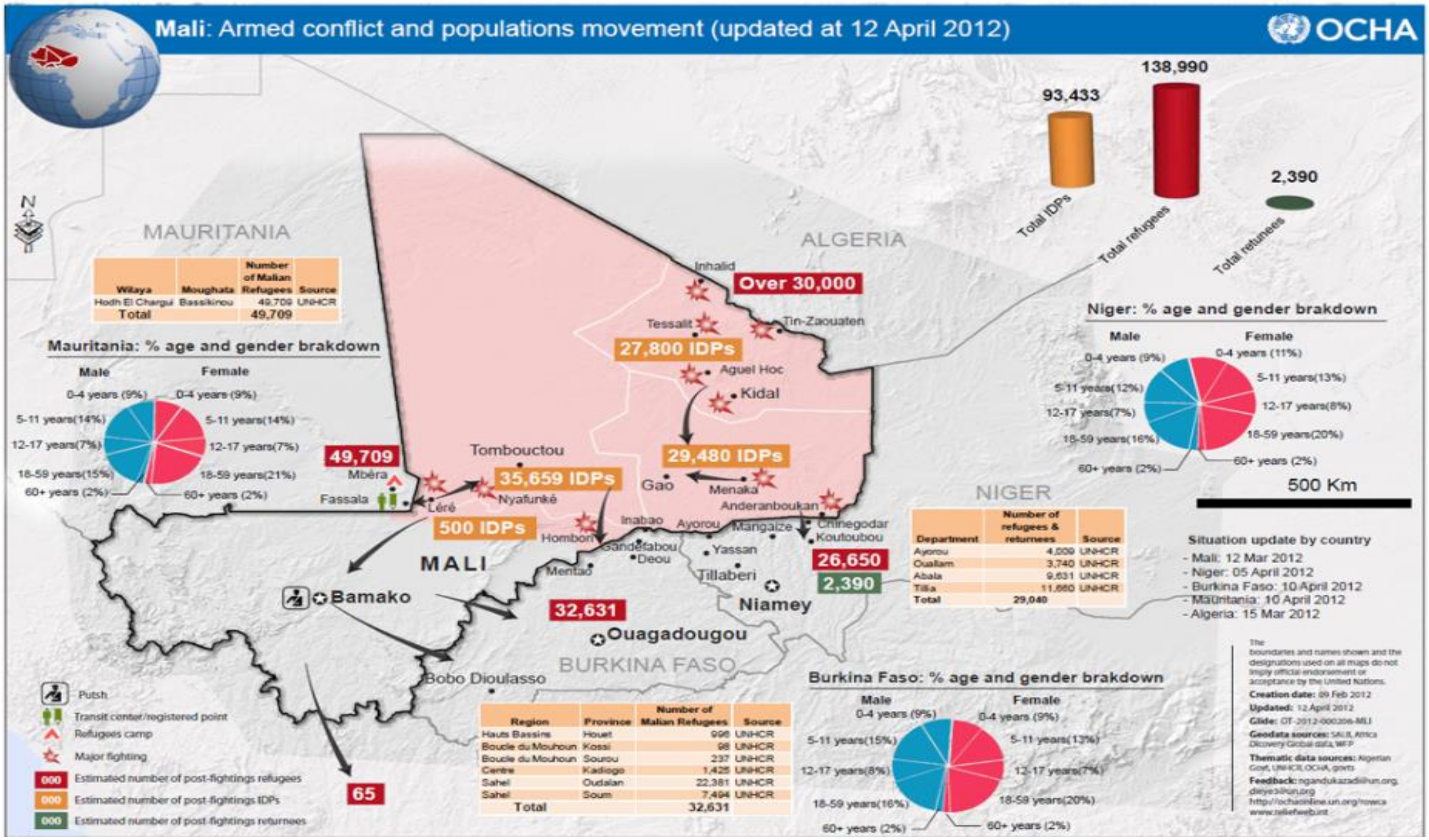

Figure 26. Factor 8: Threat Overview Map 2[133]

[133] European Country of Origin Information Network, *Mali: Armed Conflict and Populations Movement*, (https://www.ecoi.net/mali/maps.

I. SUMMARY OF COMMUNE QUALITY SCORES

Table 14 illustrates the raw data that analysts might gather to derive the c_i and c'_i for each commune.

Table 14. Summary of c_i and c'_i

				α_{i1} Pop Density				α_{i2} Existing Bodies of Water				α_{i3} Flood Frequency				α_{i4} Drought Mortality Risk				α_{i5} Cropland Intensity				α_{i6} Trade Route (Illicit)		α_{i7} vNSA Control		α_{i8} SIGACT			
c_i	Raw Population	Area [km²]	Raw Pop Density [inh./km²]	0.00	0.25	0.75	1.00	0.00	0.25	0.75	1.00	0.00	0.25	0.75	1.00	0.00	0.25	0.75	1.00	0.00	0.25	0.75	1.00	0	1	0	1	0	1	c_i	c'_i
c1	4,810	28,616	5.95			1					1	1							1				1		1		1		1	6.75	5.18
c2	17,760	20,516	1.16			1					1	1							1				1		1		1		1	6.75	6.38
c3	12,040	19,099	1.59			1		1							1			1		1					1		1		1	5.50	5.48
c4	15,960	30,409	1.91			1					1	1				1					1				1	1			1	4.00	6.15
c5	24,880	5,430	0.22			1					1				1			1					1		1		1		1	7.50	7.14
c6	22,040	5,421	0.25			1					1				1				1				1	1			1		1	6.75	5.46
c7	9,963	122,996	12.35		1						1	1					1				1				1		1		1	4.75	4.52
c8	7,930	22,285	2.81			1					1	1							1				1		1		1		1	6.75	6.35
c9	14,927	104,545	7.00		1						1	1				1						1			1	1	1		1	5.00	5.94
c10	20,960	22,659	1.08			1					1				1			1				1		1		1		1		4.25	6.82
c11	6,210	2,859	0.46			1		1							1				1	1				1			1	1		3.75	4.26
c12	6,950	18,090	2.6			1					1	1							1				1	1			1	1		4.75	3.35
c13	6,570	13,766	2.1			1					1	1							1			1			1		1		1	6.50	6.44
c14	4,880	30,263	6.2			1					1	1							1			1			1		1		1	6.50	4.67
c15	5,583	32,700	0.2			1		1							1				1				1	1		1		1		3.75	4.04
c16	3,378	8,020	0.4			1		1							1				1				1		1	1			1	5.75	4.85
c17	2,369	8,220	0.3			1		1							1				1				1		1		1	1		5.75	4.53
c18	2,595	23,090	0.1			1		1							1				1				1	1			1		1	5.75	6.15
c19	2,469	29,240	0.1			1		1							1				1				1		1		1		1	6.75	6.64
c20	7,903	13,730	0.6			1		1				1						1					1		1	1			1	4.50	6.27
c21	2,378	3,850	0.6			1		1							1				1				1		1		1	1		5.75	5.14
c22	4,549	8,480	0.5			1		1							1				1				1		1		1	1		5.75	6.93
c23	5,119	3,630	1.4			1		1							1				1				1		1		1		1	6.75	5.31
c24	25,969	9,620	2.7			1		1							1			1					1		1	1		1		4.50	5.50
c25	5,427	4,620	1.2			1		1							1				1				1	1			1		1	5.75	5.30
c26	4,398	43,500	0.1			1					1				1				1				1		1		1	1		6.75	6.10
c27	2,977	19,400	0.2			1					1				1				1				1		1		1	1		6.75	5.66
c28	4,126	26,560	0.2			1					1				1				1				1		1		1	1		6.75	4.95
c29	13,099	776	16.9	1							1	1				1							1		1		1		1	5.00	4.33
c30	11,358	7,540	1.5			1					1	1							1				1		1	1		1		4.75	5.67
c31	12,912	259,000	0.0			1		1							1	1							1		1		1		1	5.75	8.71
c32	54,629	40	1365.7	1							1	1							1				1		1		1	1		5.00	6.10
c33	21,462	33,500	0.6			1		1							1				1				1		1		1		1	6.75	4.61
c34	18,967	37,300	0.5			1		1					1						1				1		1		1		1	6.00	7.03
c35	4,477	5,940	0.8			1		1							1				1				1		1		1	1		5.75	5.20
c36	9,850	4,230	2.3			1		1							1		1						1		1		1		1	6.00	8.07
c37	17,432	1,330	13.1		1						1			1			1						1	1		1			1	4.25	3.64
c38	10,447	938	11.1		1						1	1					1						1		1		1		1	5.50	5.10
c39	16,948	1,585	10.7		1						1	1					1						1		1		1		1	5.50	5.05
c40	8,522	1,877	4.5			1		1							1		1						1		1		1		1	6.00	6.69
c41	335,256	11,982	28.0	1							1	1				1					1			1		1			1	2.25	5.01
c42	7,371	6,010	1.2			1					1	1					1						1		1		1		1	6.00	5.70
c43	16,485	2,202	7.5			1					1	1				1					1				1		1		1	5.00	3.79
c44	9,084	3,790	2.4			1					1	1					1						1		1		1		1	6.00	5.39
c45	3,557	7,770	0.5			1		1							1		1						1		1		1		1	6.00	6.12
c46	6,101	7,410	0.8			1		1							1		1						1	1			1		1	5.00	6.68
c47	24,065	13,310	1.8			1					1				1		1						1		1		1		1	7.00	5.63

APPENDIX E. SENSITIVITY ANALYSIS

In the absence of accurate data, a simulation-based sensitivity analysis of the input variables should assist the decision analyst in maximizing rehabilitation and optimally allocating projects.[134] The simulation forecasts the rehabilitation scores, by comparing two extreme scenarios to each other and to a base case.

In this setup, the simulation runs five trials (one-thousand times per trial) for each project design against all three scenarios. Also, the simulation runs trials to address three commune scenarios for each project design. Due to the uncertainty surrounding the threat level in Northern Mali, each of the scenarios has an equal chance of happening (i.e., a uniform distribution).

Without accurate data, the simulation uses a triangular distribution (see Figures 27, 30, 33, and 36) to set up for the initial Monte Carlo simulation.[135] In a worst-case scenario, the analyst should assume some minimum quality score for c_{i1}. In the likely scenario, the analyst should assume a base quality score for c_{i2}. In a best-case scenario, the analyst should assume some maximum quality score for c_{i3}. See the variable descriptions and scores below.

[134] Sensitivity analysis allows the analyst to simulate the uncertainty in the output of the IP models. The analyst can simulate the apportionment of scores along different conditions of uncertainty. Therefore, the sensitivity analysis allows the analyst to test the robustness of the IP models' outputs in the case of uncertainty. Furthermore, analysts can test the relationships between input variables and the output variables in the IP model. Commensurate with this thesis, analysts can clarify their interpretation of the IP models so that decision makers better understand the strength of the model as they collaborate with policymakers. This added level of analysis lends more credibility to the IP models, and it may give the AFRICOM commander more influence with the U.S. ambassador to Mali.

[135] The Monte Carlo method was invented by scientists working on the atomic bomb in the 1940s, who named it for the city in Monaco famed for its casinos and games of chance. Its core idea is to use random samples of parameters or inputs to explore the behavior of a complex system or process. Since that time, Monte Carlo methods have been applied to an incredibly diverse range of problems in science, engineering, and finance and business applications in virtually every industry. This Monte Carlo simulation was used to make an estimated forecast due to uncertainty. Otherwise, the IP model could be significantly inaccurate with adverse consequences. Frontline Systems, "Large-Scale LP/QP Solver Engine," Frontline Systems.

A. SIMULATED INPUT VARIABLES

The Monte Carlo simulation uses the following variables: c_{ih}, p_{jh}, and β_{hj}.

Let β_{hj} be the development scenario h for each project design j, where

$$h = \{1,2,3\} \quad \text{and} \quad j = \{1,2,3,4\}$$

$$\beta_{h1} \in \{4,5,6\}$$
$$\beta_{h2} \in \{6,7,8\}$$
$$\beta_{h3} \in \{5,6,7\}$$
$$\beta_{h4} \in \{1,2,3\}$$

The simulation assumes a uniform distribution for β_{hj}.

Let p_{jh} be the project design j for each development scenario h; where

$$j = \{1,2,3,4\} \quad \text{and} \quad h = \{1,2,3\}$$

$$p_{1h} \in [6.01, 7.00]$$
$$p_{2h} \in [7.01, 8.00]$$
$$p_{3h} \in [8.01, 9.00]$$
$$p_{4h} \in [9.01, 10.00]$$

The simulation assumes a triangular distribution for p_{jh} (see the top illustration outlined with red borders in Figures 27, 30, 33, and 36).

Let c_{ih} be the commune scenario score for each development scenario h, where

$$i = \{1,2,3,4\} \quad \text{and} \quad h = \{1,2,3\}$$

$$c_{1h} \in [1.42, 1.92]$$
$$c_{2h} \in [2.47, 2.97]$$
$$c_{3h} \in [4.61, 5.11]$$
$$c_{4h} \in [5.75, 6.00]$$

The simulation assumes a triangular distribution for c_{ih} (see the bottom illustration outlined with blue borders in Figures 27, 30, 33, and 36).

1. Simulated Coefficients

Let Q_{hij} be the simulated rehabilitation scores, where

$$Q_{hij} = \beta_{hj}(p_{jh} - c_{ih}) \in \mathbb{R}$$
$$\text{and } h = \{1,2,3\},\ i = \{1,2,3,4\},\ \text{and } j = \{1,2,3,4\} \tag{27}$$

2. Summary of Simulated Rehabilitation per Project Design Type

The Monte Carlo simulation generated the following rehabilitation scores per project design:

1. On average, Project Design 1 yielded a maximum rehabilitation of 24.2.
2. On average, Project Design 2 yielded a maximum rehabilitation of 33.5.
3. On average, Project Design 3 yielded a maximum rehabilitation of 21.9.
4. On average, Project Design 4 yielded a maximum rehabilitation of 7.29.

3. Simulated Objective Function

The simulated objective function maximizes the total value of rehabilitation.

$$Z''' = \sum_{h=1}^{3}\sum_{i=1}^{4}\sum_{j=1}^{4} Q_{hij} \tag{28}$$

Ultimately, Model I assumed an uncertain environment and determined the total maximum rehabilitation score $Z = 82.5$. The simulator forecasted a total maximum rehabilitation score $Z''' = 86.8$ for an uncertain environment.

4. Summary of Results from the Sensitivity Analysis

In a permissive environment, the total maximum rehabilitation score is approximately $Z''' = 97.4$. To achieve this amount of rehabilitation, AFRICOM would have to allocate 24 projects in the following fashion:

For Q_{1i1}, 6 projects are available.

For Q_{1i2}, 8 projects are available.

For Q_{1i3}, 7 projects are available.

For Q_{1i4}, 3 projects are available.

In an uncertain environment, the total maximum rehabilitation score is approximately $Z''' = 86.8$. To achieve this amount of rehabilitation, AFRICOM would have to allocate 20 projects in the following fashion:

For Q_{2i1}, 5 projects are available.

For Q_{2i2}, 7 projects are available.

For Q_{2i3}, 6 projects are available.

For Q_{2i4}, 2 projects are available.

In a hostile environment, the total maximum rehabilitation score is approximately $Z''' = 74.0$. To achieve this amount of rehabilitation, AFRICOM would have to allocate 16 projects in the following fashion:

For Q_{3i1}, 4 projects are available.

For Q_{3i2}, 6 projects are available.

For Q_{3i3}, 5 projects are available.

For Q_{3i4}, one project is available.

With the Monte Carlo simulation, on average, the total maximum rehabilitation score $Z''' = 86.8$. To achieve this amount of rehabilitation, AFRICOM would have to allocate 20 projects in the following fashion:

For Q_{2i1}, five projects are available.

For Q_{2i2}, seven projects are available.

For Q_{2i3}, six projects are available.

For Q_{2i4}, two projects are available.

B. PROJECT DESIGN 1: SIMULATION SETUP

Table 15 illustrates the Monte Carlo simulation setup for Project Design 1.

Table 15. Rehabilitation Forecast for Project Design 1

	A	B	C	D	E	F	G	H	I	J
1										
2		**Rehabilitation Forecast for Project Design 1**								
3										
4		**Development Scenarios β_{hl}**	**Scenario h**		**# of Proj**	**p_{1h}**		**Analysis**[1]		
5		Min β_{11} (hostile environment)	1		4	6.01		Development Scenario (β_{hl}):	2	=PsiIntUniform(1,3)
6		Likely β_{22} (uncertain environment)	2		5	6.50		No. of projects:	5	=CHOOSE(I5,E5,E6,E7)
7		Max β_{31} (permissive environment)	3		6	7.00		Development p_{1h} score	6.73	=PsiTriangular(F5,F6,F7)
8								Commune c_{1h} score	1.60	=PsiTriangular(C11,C12,C13)
9										
10		**Commune *1h* Scenarios**	**c_{ih}**		**Note**			Forecast Rehabilitation[2]		
11		Min c_{11}	1.42					Net Benefit Z‴	25.67	=I6*(I7-I8)
12		Likely c_{12}	1.67		*Derived from Model I*			Average Benefit Z‴	24.18	=PsiMean(I11)
13		Max c_{13}	1.92					Average No. of projects:	5	=PsiMean(I6)
14										
15										

The triangular distribution is a continuous probability distribution with minimum, maximum, and likely scores for p_{1h} and c_{1h}. Figure 27 illustrates the triangular distributions from Table 15.

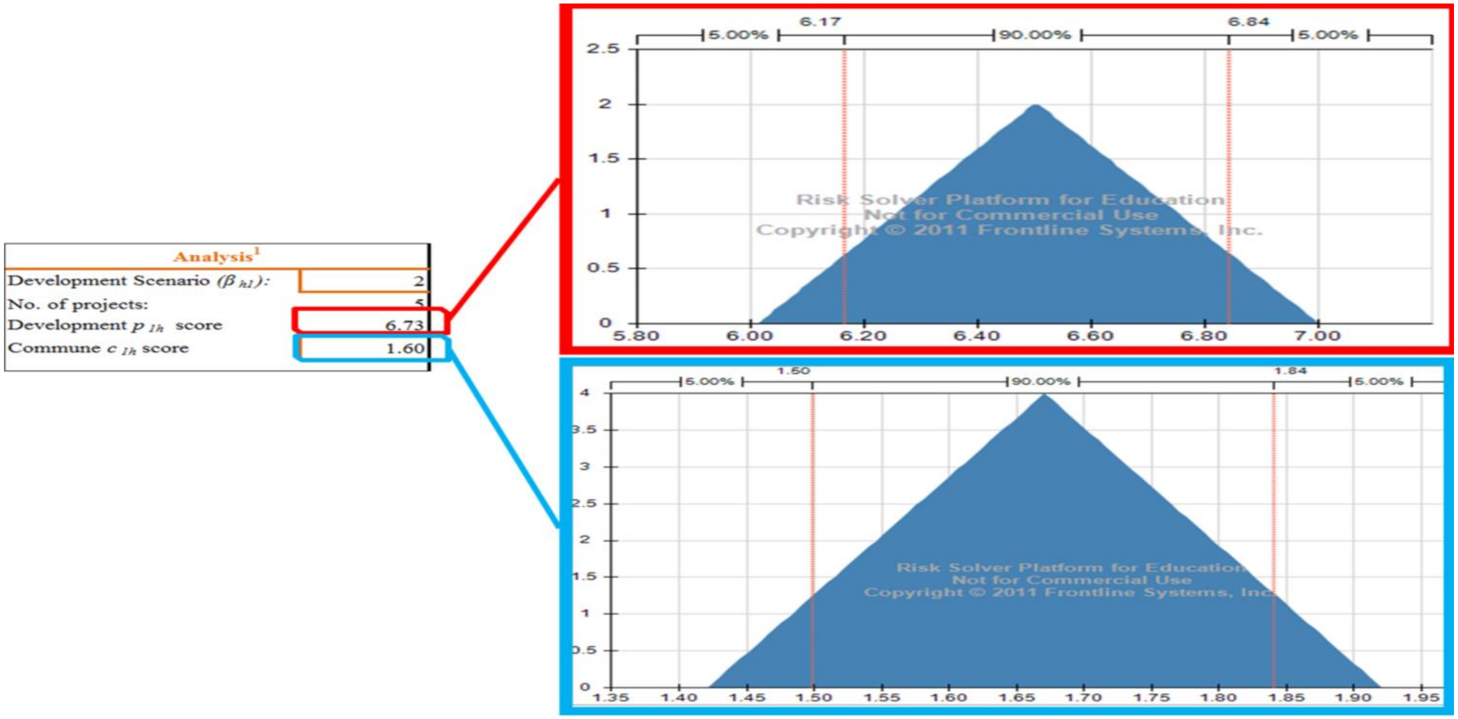

Figure 27. Triangular Distributions Project Design 1[136]

136 Frontline Systems, “Large-Scale LP/QP Solver Engine,” Frontline Systems. Figure 27 illustrates a triangular distribution for Cells I7 and I8 respectively.

The histogram in Figure 28 suggests that when the analyst sets the "lower cutoff" rehabilitation score equal to 24.0, the following occur:

1. For a permissive environment, the maximum amount of rehabilitation would be approximately 32.7(a 50.7 percent chance).
2. For an uncertain environment, the likely amount of rehabilitation would be approximately 24.2.
3. For a hostile environment, the minimum amount of rehabilitation would be approximately 16.9 (a 49.3 percent chance).

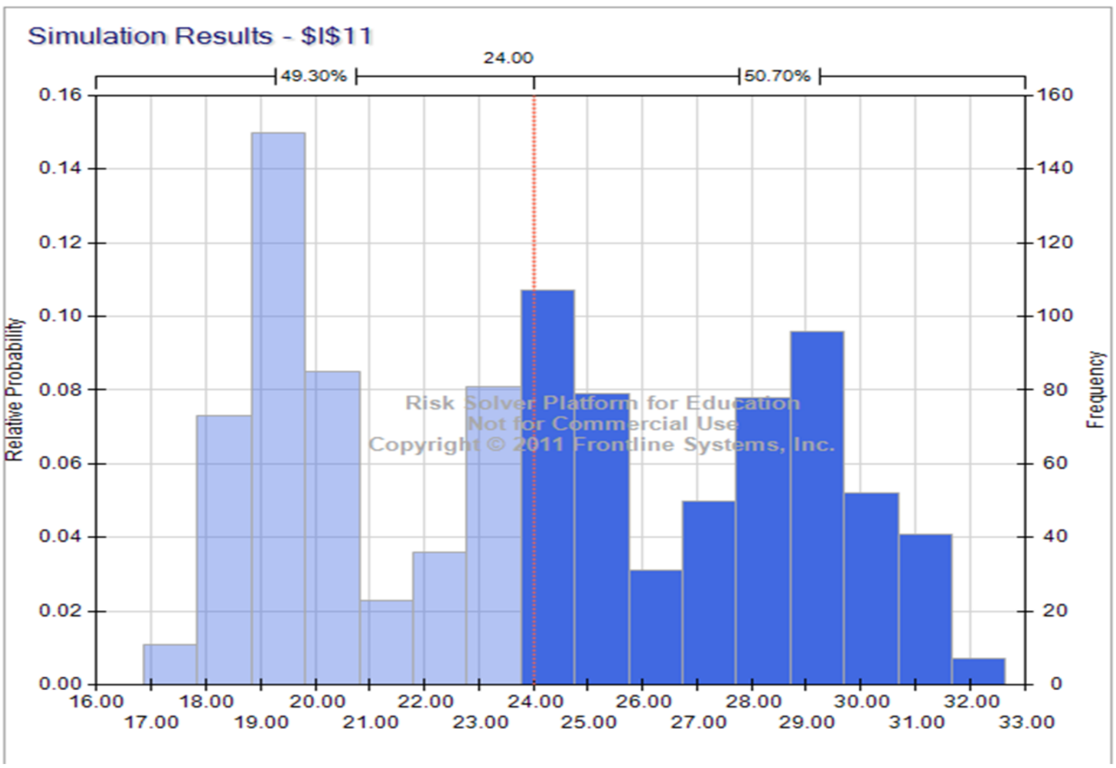

Figure 28. Project Design 1: Analysis of Forecasted Rehabilitation[137]

The sensitivity analysis in Figure 29 suggests that the development scenario (or Cell: I5) has a more significant impact than the scores for p_{1h} and c_{1h} (Cells I7 and I8 respectively). Ultimately the threat level of the environment has a bigger impact than the

137 Ibid.

scores for communes and projects. However, the project score has a larger impact than the commune score. Figure 29 is a sensitivity analysis of the input data for communes receiving Project Design 1.

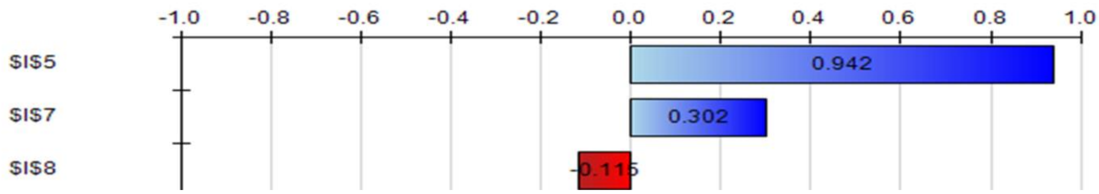

Figure 29. Project Design 1: Sensitivity Analysis of Forecasted Rehabilitation[138]

C. PROJECT DESIGN 2: SIMULATION SETUP

Table 16 illustrates the Monte Carlo simulation setup for Project Design 2.

Table 16. Rehabilitation Forecast for Project Design 2

	B	C	E	F	H	I	J
1							
2	**Rehabilitation Forecast for Project Design 2**						
3							
4	**Development Scenarios β_{h2}**	**Scenario h**	**# of Proj**	**p_{2h}**	**Analysis[1]**		
5	Min β_{12} (hostile environment)	1	6	7.01	Development Scenario (β_{h2}):	3	=PsiIntUniform(1,3)
6	Likely β_{22} (uncertain environment)	2	7	7.50	No. of projects:	8	=CHOOSE(I5,E5,E6,E7)
7	Max β_{32} (permissive environment)	3	8	8.00	Development p_{2h} score	7.35	=PsiTriangular(F5,F6,F7)
8					Commune c_{2h} score	2.82	=PsiTriangular(C11,C12,C13)
9							
10	**Commune $2h$ Scenarios**	**c_{ik}**	**Note**		Forecast Rehabilitation[2]		
11	Min c_{21}	2.47			Net Benefit Z_i'''	36.22	=I6*(I7-I8)
12	Likely c_{22}	2.72	*Derived from Model I*		Average Benefit Z'''	33.48	=PsiMean(I11)
13	Max c_{23}	2.97			Average No. of projects:	7	=PsiMean(I6)
14							
15							

138 Ibid.

The triangular distribution is a continuous probability distribution with minimum, maximum, and likely scores for p_{2h} and c_{2h}. Figure 30 illustrates the triangular distributions from Table 16.

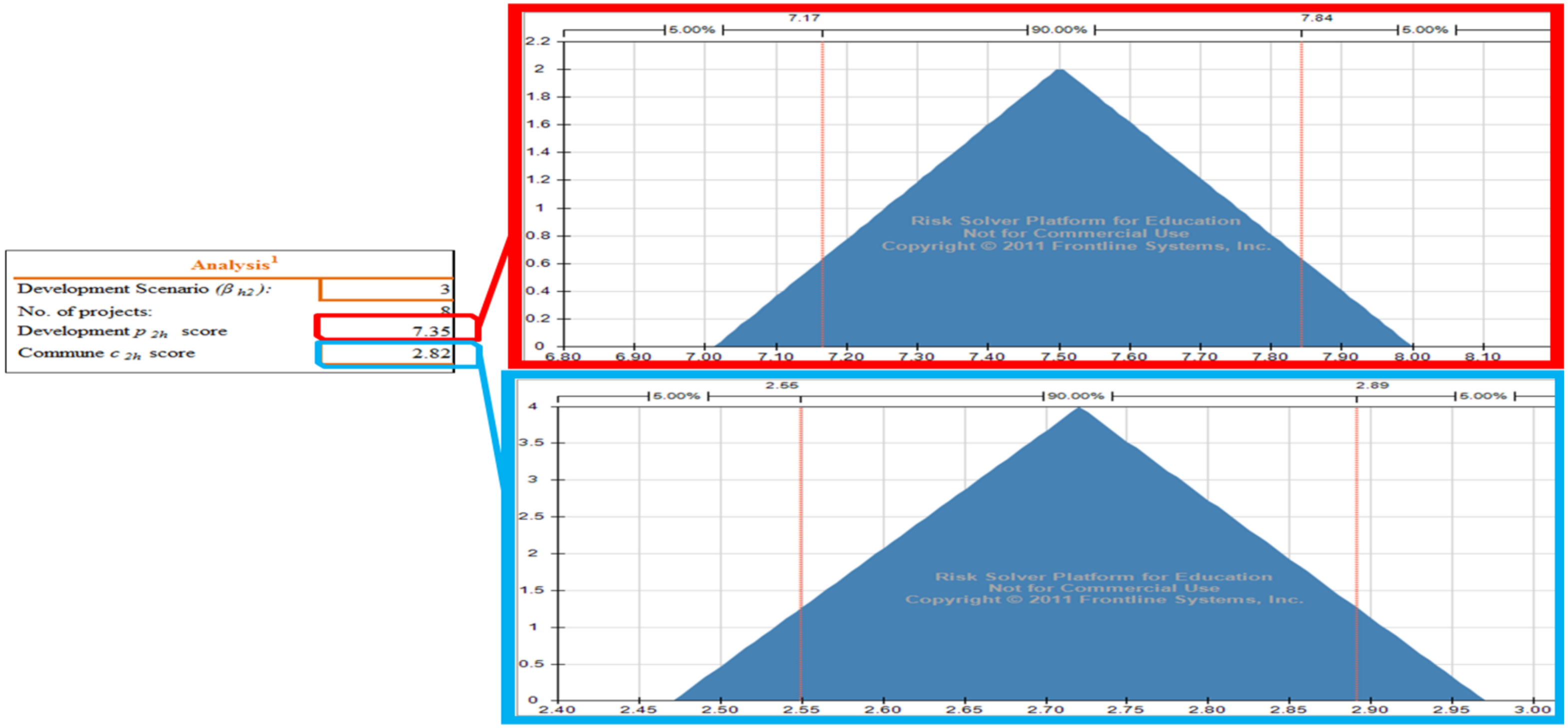

Figure 30. Triangular Distributions Project Design 2[139]

139 Ibid. Figure 30 illustrates a triangular distribution for Cells I7 and I8 respectively.

The histogram in Figure 31 reflects the rehabilitation scores for Project Design 2.

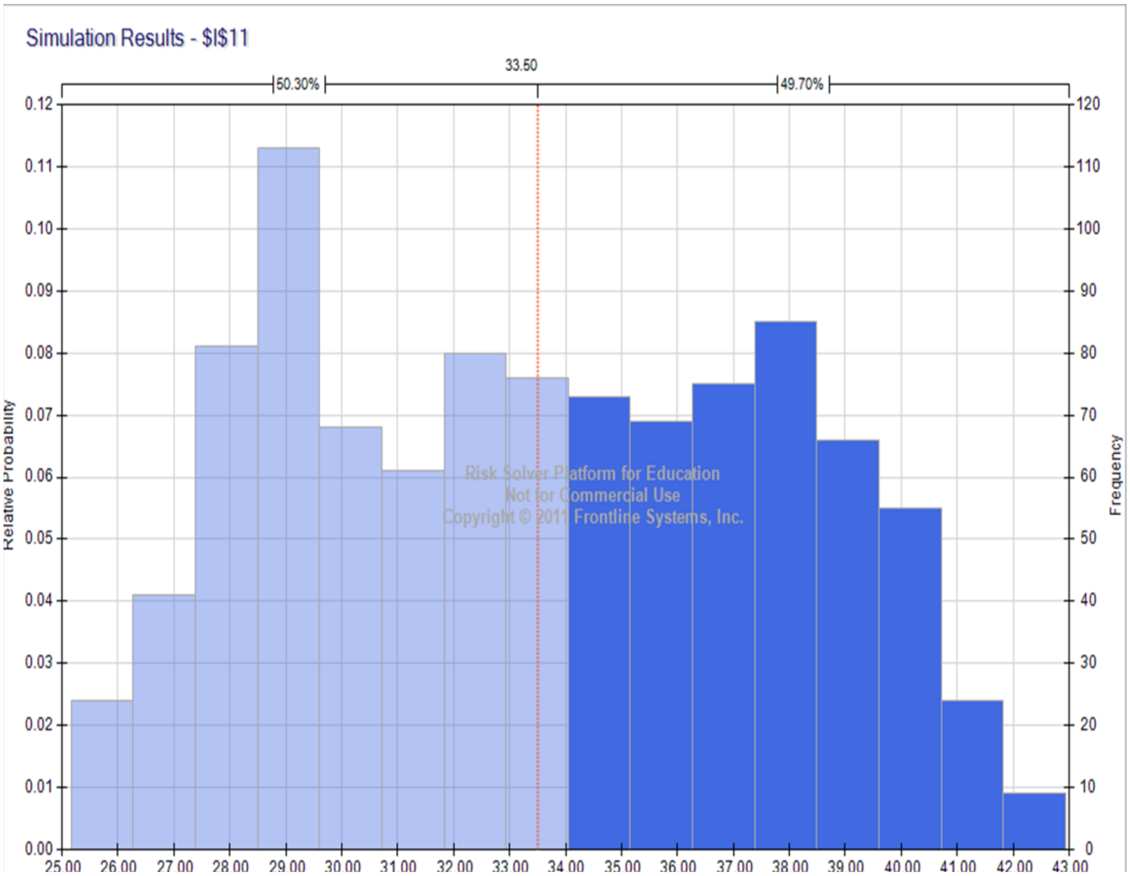

Figure 31. Project Design 2: Analysis of Forecasted Rehabilitation[140]

The histogram in Figure 31 suggests that when the analyst sets the "lower cutoff" rehabilitation score equal to 33.5, the following occur:

4. For a permissive environment, the maximum amount of rehabilitation would be approximately 42.9 (a 49.7 percent chance).

5. For an uncertain environment, the likely amount of rehabilitation would be approximately 33.5.

6. For a hostile environment, the minimum amount of rehabilitation would be approximately 25.2 (a 50.3 percent chance).

The sensitivity analysis in Figure 16 suggests that the development scenario (or Cell: I5) has a more significant impact than the scores for p_{2h} and c_{2h} (Cells I7 and I8

[140] Ibid.

respectively). Ultimately the threat level of the environment has a bigger impact than the scores for communes and projects. However, the project score has a larger impact than the commune score. Figure 32 is a sensitivity analysis of the input data for communes receiving Project Design 2.

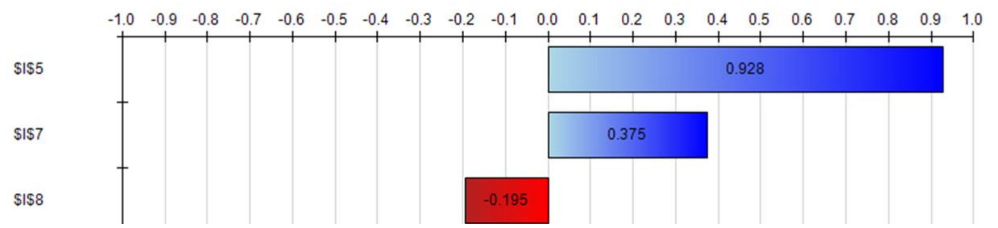

Figure 32. Project Design 2: Sensitivity Analysis of Forecasted Rehabilitation[141]

D. PROJECT DESIGN 3: SIMULATION SETUP

Table 17 illustrates the Monte Carlo simulation setup for Project Design 3.

Table 17. Rehabilitation Forecast for Project Design 3

Rehabilitation Forecast for Project Design 3						
Development Scenarios β_{h3}	**Scenario h**	**# of Proj**	**p_{3h}**	**Analysis[1]**		
Min β_{13} (hostile environment)	1	5	8.01	Development Scenario (β_{h3}) :	2	=PsiIntUniform(1,3)
Likely β_{23} (uncertain environment)	2	6	8.50	No. of projects:	6	=CHOOSE(I5,E5,E6,E7)
Max β_{33} (permissive environment)	3	7	9.00	Development p_{3h} score	8.37	=PsiTriangular(F5,F6,F7)
				Commune c_{3h} score	4.79	=PsiTriangular(C11,C12,C13)
Commune $3h$ Scenarios	**c_{ih}**	**Note**		**Forecast Rehabilitation[2]**		
Min c_{31}	4.61			Net Benefit Z'''	21.48	=I6*(I7-I8)
Likely c_{32}	4.86	*Derived from Model I*		Average Benefit Z'''	21.86	=PsiMean(I11)
Max c_{33}	5.11			Average No. of projects:	6	=PsiMean(I6)

141 Ibid.

The triangular distribution is a continuous probability distribution with minimum, maximum, and likely scores for p_{3h} and c_{3h}. Figure 33 illustrates the triangular distributions from Table 17.

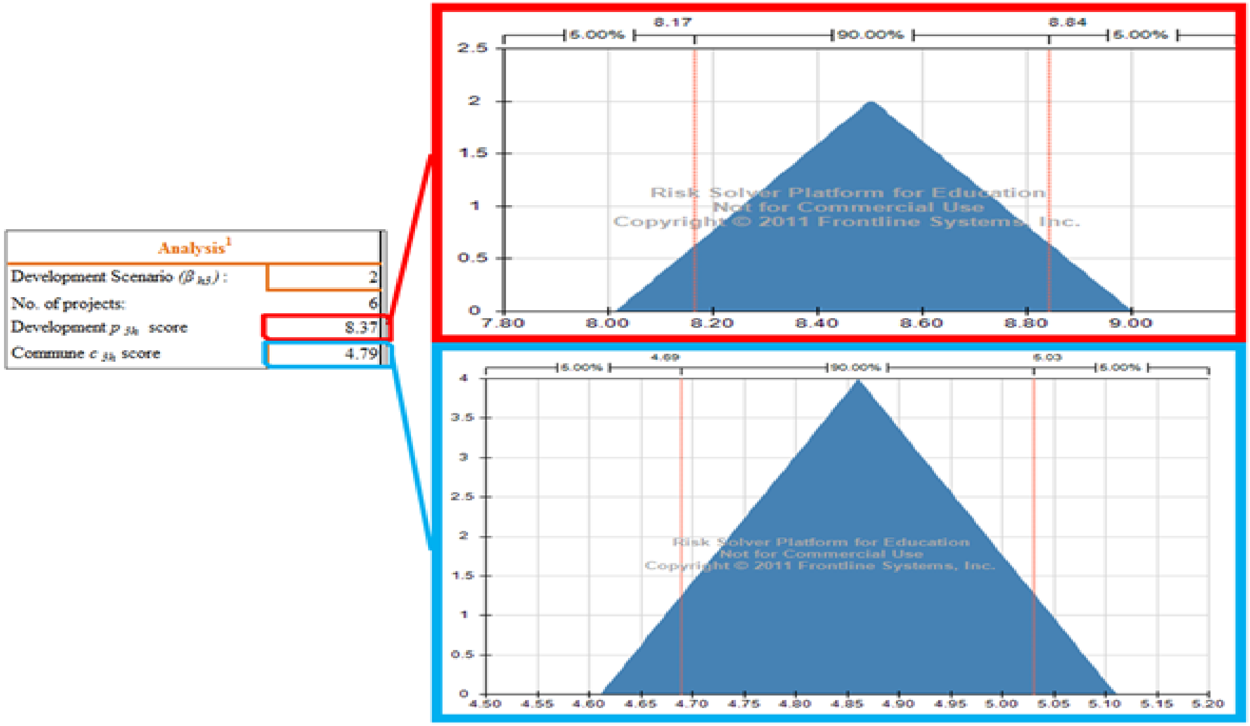

Figure 33. Triangular Distributions Project Design 3[142]

142 Ibid. Figure 33 illustrates a triangular distribution for Cells I7 and I8 respectively.

The histogram in Figure 34 reflects the rehabilitation scores for Project Design 3.

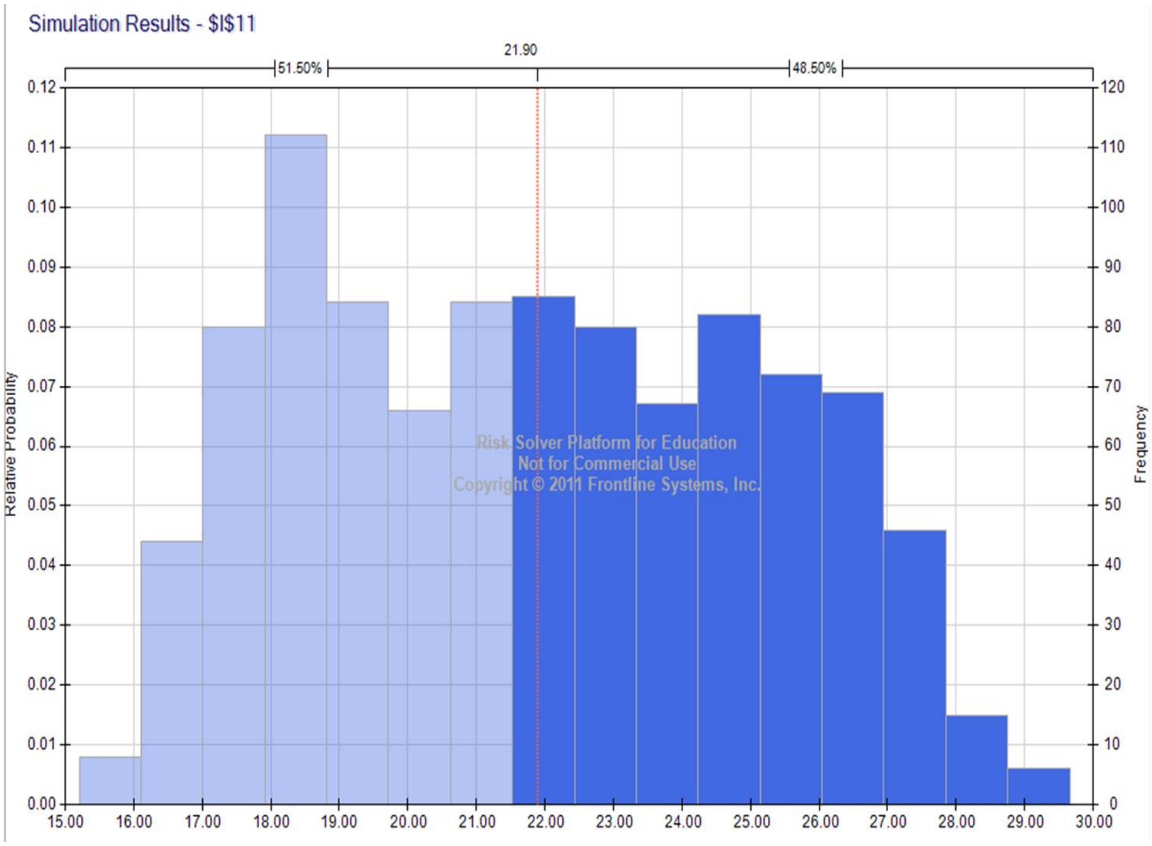

Figure 34. Project Design 3: Analysis of Forecasted Rehabilitation[143]

The histogram in Figure 34 suggests that when the analyst sets the "lower cutoff" rehabilitation score equal to 21.9, the following occur:

1. For a permissive environment, the maximum amount of rehabilitation would be approximately 29.7 (a 48.5 percent chance).
2. For an uncertain environment, the likely amount of rehabilitation would be approximately 21.9.
3. For a hostile environment, the minimum amount of rehabilitation would be approximately 15.2 (a 51.5 percent chance).

The sensitivity analysis in Figure 35 suggests that the development scenario (or Cell: I5) has a more significant impact than the scores for p_{3h} and c_{3h} (Cells I7 and I8

143 Ibid.

respectively). Ultimately the threat level of the environment has a bigger impact than the scores for communes and projects. However, the project score has a larger impact than the commune score. Figure 35 is a sensitivity analysis of the input data for communes receiving Project Design 3.

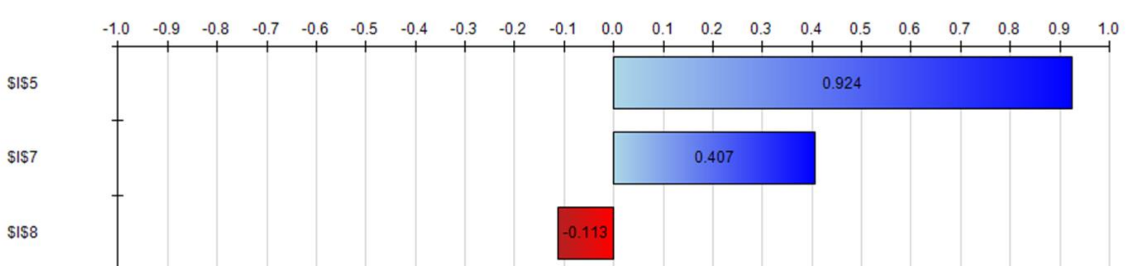

Figure 35. Project Design 3: Sensitivity Analysis of Forecasted Rehabilitation[144]

E. PROJECT DESIGN 4: SIMULATION SETUP

Table 18 illustrates the Monte Carlo simulation setup for Project Design 4.

Table 18. Rehabilitation Forecast for Project Design 4

	A	B	C	E	F	G	H	I	J
1									
2		**Rehabilitation Forecast for Project Design 4**							
3									
4		**Development Scenarios β_{h4}**	**Scenario h**	**# of Proj**	**p_{4h}**		Analysis[1]		
5		Min β_{14} (hostile environment)	1	1	9.01		Development Scenario (β_{h4}):	3	=PsiIntUniform(1,3)
6		Likely β_{24} (uncertain environment)	2	2	9.50		No. of projects:	3	=CHOOSE(I5,E5,E6,E7)
7		Max β_{34} (permissive environment)	3	3	10.00		Development p_{4h} score	9.44	=PsiTriangular(F5,F6,F7)
8							Commune c_{4h} score	5.82	=PsiTriangular(C11,C12,C13)
9									
10		**Commune 4h Scenarios**	**c_{ik}**	**Note**			Forecast Rehabilitation[2]		
11		Min c_{41}	5.75				Net Benefit Z'''	10.86	=I6*(I7-I8)
12		Likely c_{42}	5.83	*Derived from Model I*			Average Benefit Z'''	7.29	=PsiMean(I11)
13		Max c_{43}	6.00				Average No. of projects:	2	=PsiMean(I6)
14									
15									

144 Ibid.

The triangular distribution is a continuous probability distribution with minimum, maximum, and likely scores for p_{4h} and c_{4h}. Figure 36 illustrates the triangular distributions from Table 18.

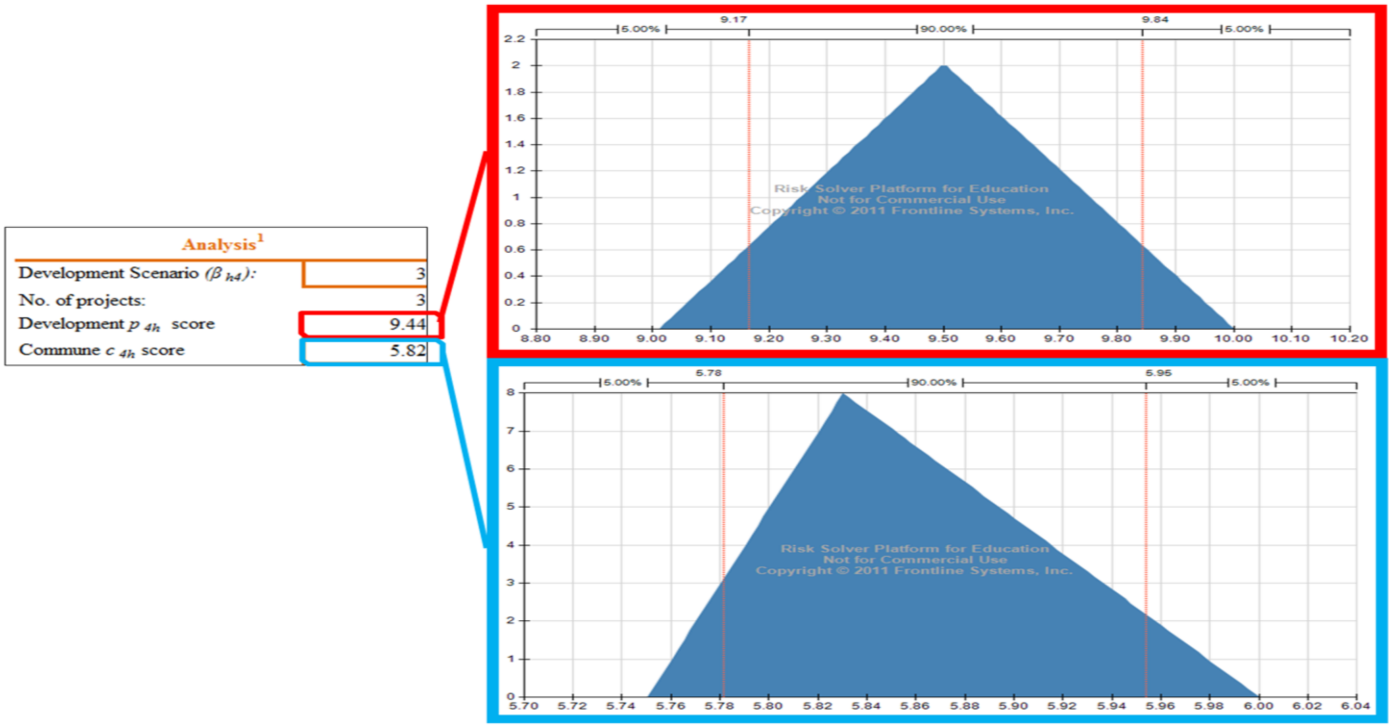

Figure 36. Triangular Distributions Project Design 3[145]

[145] Ibid. Figure 20 illustrates a triangular distribution for Cells I7 and I8 respectively.

The histogram in Figure 37 reflects the rehabilitation scores for Project Design 4.

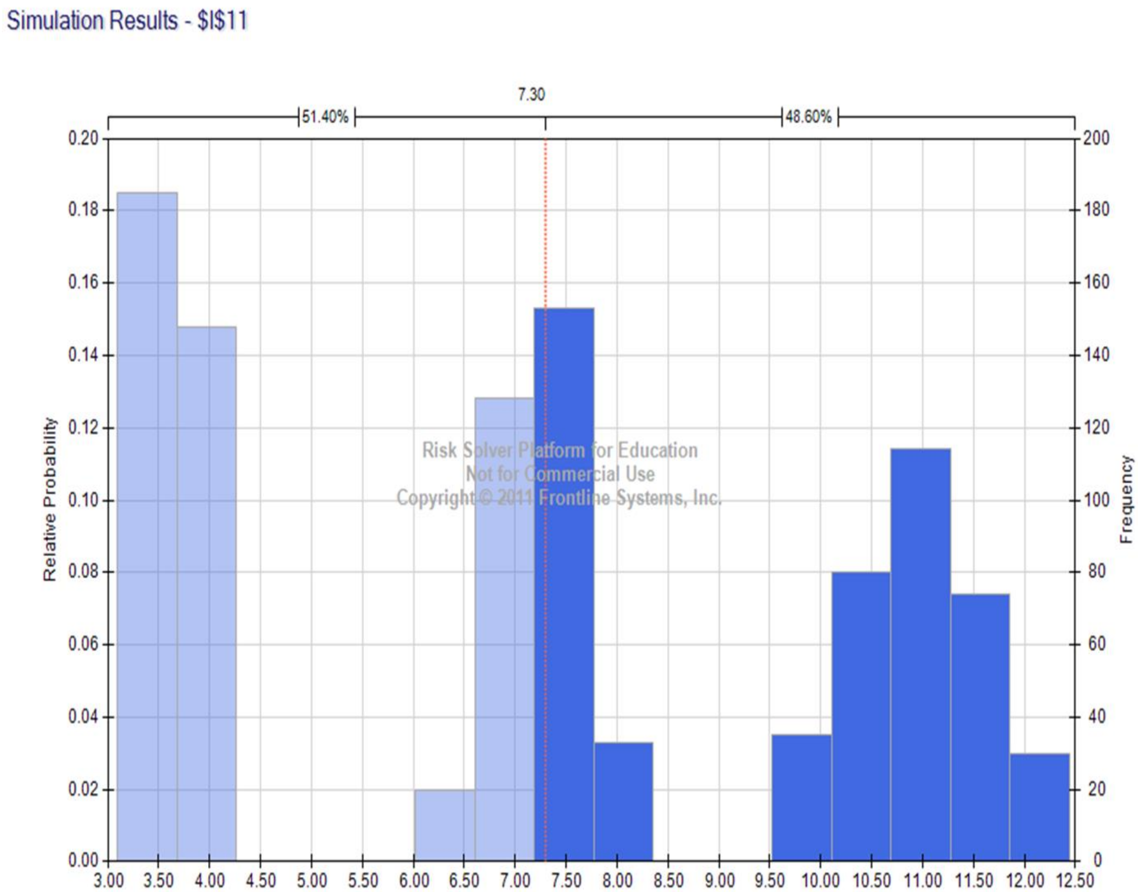

Figure 37. Project Design 4: Analysis of Forecasted Rehabilitation[146]

The histogram in Figure 37 suggests that when the analyst sets the “lower cutoff” rehabilitation score equal to 7.30, the following occur:

1. For a permissive environment, the maximum amount of rehabilitation would be approximately 12.4 (a 48.6 percent chance).
2. For an uncertain environment, the likely amount of rehabilitation would be approximately 7.29.
3. For a hostile environment, the minimum amount of rehabilitation would be approximately 3.10 (a 51.4 percent chance).

[146] Ibid.

The sensitivity analysis in Figure 38 suggests that the development scenario (or Cell: I5) has a more significant impact than the scores for p_{4h} and c_{4h} (Cells I7 and I8 respectively). Ultimately the threat level of the environment has a bigger impact than the scores for communes and projects. However, the project score has a larger impact than the commune score. Figure 38 is a sensitivity analysis of the input data for communes receiving Project Design 4.

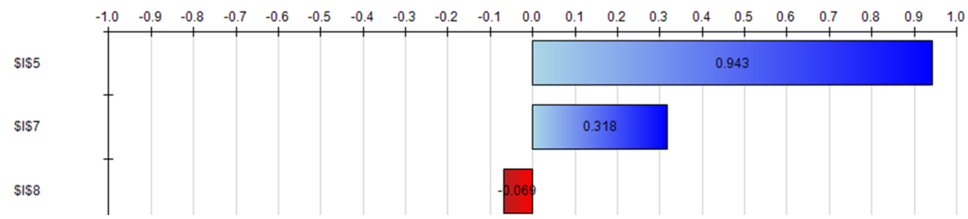

Figure 38. Project Design 4: Sensitivity Analysis of Forecasted Rehabilitation[147]

[147] Ibid.

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APPENDIX F. DETAILED SETUP OF MODEL I

This Appendix outlines the detail calculations for Chapter VI, Section B.

A. SETS AND INDICES IN DETAIL

Let c_i be the quality score for each commune *i*; where

$$c_i \in [0,8] \text{ and } i = \{1,...,47\}$$

$$c_i = \sum_{j=1}^{8} \alpha_{qi} \tag{29}$$

$$\alpha_{qi} = \text{ quality score } j \text{ for commune } i$$

Let p_j be the quality score for each project *j*; where

$$p_j \in \{7,8,9,10\} \text{ and } j = \{1,2,3,4\}$$

$$\begin{aligned} p_1 &= 7 \\ p_2 &= 8 \\ p_3 &= 9 \\ p_4 &= 10 \end{aligned} \tag{30}$$

For projects denoted as p_1, 6 projects are available.

For projects denoted as p_2, 8 projects are available.

For projects denoted as p_3, 7 projects are available.

For projects denoted as p_4, 3 projects are available.

In all, there are a total of 24 projects available.

B. COEFFICIENTS

Let Q_{ij} be the rehabilitation score, which is the difference between the quality scores for project *j* and commune *i*.

$$Q_{ij} = (p_j - c_i) \in \mathbb{R}$$
$$\text{and} \quad i = \{1, ..., 47\},\ j = \{1, 2, 3, 4\} \tag{31}$$

C. DECISION VARIABLES

The optimization model uses x_{ij} for its decision variables.

Let x_{ij} be the binary decision variable,

$$\text{where } x_{ij} = \begin{cases} 1 & \text{if project } p_j \text{ is assigned to commune } i \\ 0 & \text{otherwise} \end{cases}$$
$$\text{and} \quad i = \{1, ..., 47\},\ j = \{1, 2, 3, 4\} \tag{32}$$

D. OBJECTIVE FUNCTION

The objective function maximizes the total value of rehabilitation.

$$Max = \sum_{j=1}^{4} \sum_{i=1}^{47} Q_{ij} x_{ij} \tag{33}$$

E. CONSTRAINTS

Equations 34 to 80 are covering constraints ensuring that each commune *i* is served by at least one project *j*

Covering, *commune* 1 is served by a project(s)
$$(x_{1j} + x_{2j} + x_{32j} + x_{34j} + x_{46j}) \geq 1 \tag{34}$$
Covering, *commune* 2 is served by a project(s)
$$(x_{1j} + x_{2j} + x_{3j} + x_{7j} + x_{19j} + x_{34j} + x_{46j}) \geq 1 \tag{35}$$
Covering, *commune* 3 is served by a project(s)
$$(x_{2j} + x_{3j} + x_{4j} + x_{7j} + x_{19j} + x_{20j} + x_{23j}) \geq 1 \tag{36}$$
Covering, *commune* 4 is served by a project(s)
$$\left(x_{3j} + x_{4j} + x_{5j} + x_{7j} + x_{8j} + x_{9j} + x_{13j} + x_{23j} + x_{24j}\right) \geq 1 \tag{37}$$
Covering, *commune* 5 is served by a project(s)
$$\left(x_{4j} + x_{5j} + x_{6j} + x_{9j} + x_{10j} + x_{18j} + x_{24j} + x_{25j}\right) \geq 1 \tag{38}$$

Covering, *commune* 6 is served by a project(s)

$$(x_{5j} + x_{6j} + x_{10j} + x_{11j} + x_{18j}) \geq 1 \tag{39}$$

Covering, *commune* 7 is served by a project(s)

$$\left(x_{2j} + x_{3j} + x_{4j} + x_{7j} + x_{8j} + x_{46j}\right) \geq 1 \tag{40}$$

Covering, *commune* 8 is served by a project(s)

$$(x_{4j} + x_{7j} + x_{8j} + x_{9j} + x_{13j} + x_{46j} + x_{47j}) \geq 1 \tag{41}$$

Covering, *commune* 9 is served by a project(s)

$$(x_{4j} + x_{5j} + x_{8j} + x_{9j} + x_{10j} + x_{13j} + x_{14j}) \geq 1 \tag{42}$$

Covering, *commune* 10 is served by a project(s)

$$(x_{5j} + x_{6j} + x_{9j} + x_{10j} + x_{11j} + x_{12j} + x_{14j}) \geq 1 \tag{43}$$

Covering, *commune* 11 is served by a project(s)

$$(x_{6j} + x_{10j} + x_{11j} + x_{12j}) \geq 1 \tag{44}$$

Covering, *commune* 12 is served by a project(s)

$$(x_{10j} + x_{11j} + x_{12j}) \geq 1 \tag{45}$$

Covering, *commune* 13 is served by a project(s)

$$(x_{4j} + x_{8j} + x_{9j} + x_{13j} + x_{14j} + x_{47j}) \geq 1 \tag{46}$$

Covering, *commune* 14 is served by a project(s)

$$(x_{9j} + x_{10j} + x_{13j} + x_{14j}) \geq 1 \tag{47}$$

Covering, *commune* 15 is served by a project(s)

$$(x_{15j} + x_{16j} + x_{19j} + x_{20j} + x_{22j} + x_{31j}) \geq 1 \tag{48}$$

Covering, *commune* 16 is served by a project(s)

$$(x_{15j} + x_{16j} + x_{17j} + x_{20j} + x_{22j}) \geq 1 \tag{49}$$

Covering, *commune* 17 is served by a project(s)

$$(x_{16j} + x_{17j} + x_{18j} + x_{22j}) \geq 1 \tag{50}$$

Covering, *commune* 18 is served by a project(s)

$$(x_{5j} + x_{6j} + x_{17j} + x_{18j} + x_{22j} + x_{25j}) \geq 1 \tag{51}$$

Covering, *commune* 19 is served by a project(s)

$$(x_{2j} + x_{3j} + x_{15j} + x_{19j} + x_{20j} + x_{31j} + x_{33j} + x_{34j}) \geq 1 \tag{52}$$

Covering, *commune* 20 is served by a project(s)

$$(x_{3j} + x_{15j} + x_{16j} + x_{19j} + x_{20j} + x_{21j} + x_{22j} + x_{23j} + x_{24j}) \geq 1 \tag{53}$$

Covering, *commune* 21 is served by a project(s)

$$\left(x_{20j} + x_{21j} + x_{22j} + x_{23j} + x_{24j} + x_{25j}\right) \geq 1 \tag{54}$$

Covering, *commune* 22 is served by a project(s)

$$(x_{15j} + x_{16j} + x_{17j} + x_{18j} + x_{20j} + x_{21j} + x_{22j} + x_{24j} + x_{25j}) \geq 1 \tag{55}$$

Covering, *commune* 23 is served by a project(s)

$$\left(x_{3j} + x_{4j} + x_{20j} + x_{21j} + x_{23j} + x_{24j}\right) \geq 1 \tag{56}$$

Covering, *commune* 24 is served by a project(s)

$$(x_{4j} + x_{5j} + x_{20j} + x_{21j} + x_{23j} + x_{24j} + x_{25j}) \geq 1 \tag{57}$$

Covering, *commune* 25 is served by a project(s)

$$(x_{5j} + x_{18j} + x_{21j} + x_{22j} + x_{24j} + x_{25j}) \geq 1 \tag{58}$$

Covering, *commune* 26 is served by a project(s)

$$(x_{26j} + x_{27j} + x_{31j} + x_{35j}) \geq 1 \tag{59}$$

Covering, *commune* 27 is served by a project(s)

$$(x_{26j} + x_{27j} + x_{28j} + x_{31j} + x_{40j}) \geq 1 \tag{60}$$

Covering, *commune* 28 is served by a project(s)

$$(x_{27j} + x_{28j} + x_{29j} + x_{31j} + x_{41j}) \geq 1 \tag{61}$$

Covering, *commune* 29 is served by a project(s)

$$\left(x_{28j} + x_{29j} + x_{30j} + x_{31j} + x_{32j} + x_{40j} + x_{41j}\right) \geq 1 \tag{62}$$

Covering, *commune* 30 is served by a project(s)

$$(x_{29j} + x_{30j} + x_{31j} + x_{34j} + x_{42j} + x_{44j}) \geq 1 \tag{63}$$

Covering, *commune* 31 is served by a project(s)

$$(x_{15j} + x_{19j} + x_{26j} + x_{27j} + x_{28j} + x_{29j} + x_{30j} + x_{31j} + x_{33j} + x_{34j}) \geq 1 \tag{64}$$

Covering, *commune* 32 is served by a project(s)

$$\left(x_{1j} + x_{30j} + x_{32j} + x_{34j} + x_{44j} + x_{46j}\right) \geq 1 \tag{65}$$

Covering, *commune* 33 is served by a project(s)

$$(x_{19j} + x_{30j} + x_{31j} + x_{33j} + x_{34j}) \geq 1 \tag{66}$$

Covering, *commune* 34 is served by a project(s)

$$(x_{1j} + x_{2j} + x_{19j} + x_{30j} + x_{31j} + x_{32j} + x_{33j} + x_{34j}) \geq 1 \tag{67}$$

Covering, *commune* 35 is served by a project(s)

$$(x_{26j} + x_{35j} + x_{36j} + x_{40j}) \geq 1 \tag{68}$$

Covering, *commune* 36 is served by a project(s)

$$(x_{35j} + x_{36j} + x_{37j} + x_{38j} + x_{39j} + x_{40j}) \geq 1 \tag{69}$$

Covering, *commune* 37 is served by a project(s)

$$(x_{36j} + x_{37j} + x_{38j}) \geq 1 \tag{70}$$

Covering, *commune* 38 is served by a project(s)

$$(x_{36j} + x_{37j} + x_{38j} + x_{39j}) \geq 1 \tag{71}$$

Covering, *commune* 39 is served by a project(s)

$$(x_{36j} + x_{38j} + x_{39j} + x_{40j} + x_{41j}) \geq 1 \tag{72}$$

Covering, *commune* 40 is served by a project(s)

$$(x_{26j} + x_{35j} + x_{36j} + x_{39j} + x_{40j} + x_{41j}) \geq 1 \tag{73}$$

Covering, *commune* 41 is served by a project(s)

$$(x_{29j} + x_{30j} + x_{39j} + x_{40j} + x_{41j} + x_{42j} + x_{43j}) \geq 1 \tag{74}$$

Covering, *commune* 42 is served by a project(s)

$$(x_{30j} + x_{32j} + x_{41j} + x_{42j} + x_{43j} + x_{44j} + x_{45j}) \geq 1 \tag{75}$$

Covering, *commune* 43 is served by a project(s)

$$(x_{41j} + x_{42j} + x_{43j} + x_{45j}) \geq 1 \tag{76}$$

Covering, *commune* 44 is served by a project(s)

$$(x_{30j} + x_{32j} + x_{42j} + x_{44j} + x_{45j} + x_{46j}) \geq 1 \tag{77}$$

Covering, *commune* 45 is served by a project(s)

$$\left(x_{42j} + x_{43j} + x_{44j} + x_{45j} + x_{46j} + x_{47j}\right) \geq 1 \tag{78}$$

Covering, *commune* 46 is served by a project(s)

$$(x_{1j} + x_{2j} + x_{7j} + x_{8j} + x_{32j} + x_{44j} + x_{45j} + x_{46j} + x_{47j}) \geq 1 \tag{79}$$

Covering, *commune* 47 is served by a project(s)

$$(x_{8j} + x_{13j} + x_{45j} + x_{46j} + x_{47j}) \geq 1 \tag{80}$$

Equations 81 to 84 are supply constraints ensuring that every project *j* is assigned to at most one commune *i*.

Supply of project $j = 1$, of which 6 are available

$$\begin{pmatrix} x_{11} + x_{21} + x_{31} + x_{41} + x_{51} + x_{61} + x_{71} + x_{81} + x_{91} + x_{101} + x_{111} + x_{121} + x_{131} + \\ x_{141} + x_{151} + x_{161} + x_{171} + x_{181} + x_{191} + x_{201} + x_{211} + x_{221} + x_{231} + x_{241} + x_{251} + \\ x_{261} + x_{271} + x_{281} + x_{291} + x_{301} + x_{311} + x_{321} + x_{331} + x_{341} + x_{351} + x_{361} + x_{371} + \\ x_{381} + x_{391} + x_{401} + x_{411} + x_{421} + x_{431} + x_{441} + x_{451} + x_{461} + x_{471} \end{pmatrix} = 6 \tag{81}$$

Supply of project $j = 2$, of which 8 are available

$$\begin{pmatrix} x_{12}+x_{22}+x_{32}+x_{42}+x_{52}+x_{62}+x_{72}+x_{82}+x_{92}+x_{102}+x_{112}+x_{122}+x_{132}+ \\ x_{142}+x_{152}+x_{162}+x_{172}+x_{182}+x_{192}+x_{202}+x_{212}+x_{222}+x_{232}+x_{242}+x_{252}+ \\ x_{262}+x_{272}+x_{282}+x_{292}+x_{302}+x_{312}+x_{322}+x_{332}+x_{342}+x_{352}+x_{362}+x_{372}+ \\ x_{382}+x_{392}+x_{402}+x_{412}+x_{422}+x_{432}+x_{442}+x_{452}+x_{462}+x_{472} \end{pmatrix} = 8 \qquad (82)$$

Supply of project $j = 3$, of which 7 are available

$$\begin{pmatrix} x_{13}+x_{23}+x_{33}+x_{43}+x_{53}+x_{63}+x_{73}+x_{83}+x_{93}+x_{103}+x_{113}+x_{123}+x_{133}+ \\ x_{143}+x_{153}+x_{163}+x_{173}+x_{183}+x_{193}+x_{203}+x_{213}+x_{223}+x_{233}+x_{243}+x_{253}+ \\ x_{263}+x_{273}+x_{283}+x_{293}+x_{303}+x_{313}+x_{323}+x_{333}+x_{343}+x_{353}+x_{363}+x_{373}+ \\ x_{383}+x_{393}+x_{403}+x_{413}+x_{423}+x_{433}+x_{443}+x_{453}+x_{463}+x_{473} \end{pmatrix} = 7 \qquad (83)$$

Supply of project $j = 4$, of which 3 are available

$$\begin{pmatrix} x_{14}+x_{24}+x_{34}+x_{44}+x_{54}+x_{64}+x_{74}+x_{84}+x_{94}+x_{104}+x_{114}+x_{124}+x_{134}+ \\ x_{144}+x_{154}+x_{164}+x_{174}+x_{184}+x_{194}+x_{204}+x_{214}+x_{224}+x_{234}+x_{244}+x_{254}+ \\ x_{264}+x_{274}+x_{284}+x_{294}+x_{304}+x_{314}+x_{324}+x_{334}+x_{344}+x_{354}+x_{364}+x_{374}+ \\ x_{384}+x_{394}+x_{404}+x_{414}+x_{424}+x_{434}+x_{444}+x_{454}+x_{464}+x_{474} \end{pmatrix} = 3 \qquad (84)$$

Equations 85 to 131 are demand constraints, ensuring that every commune *i* receives at most one project *j*.

Demand from *commune* 1 for project $j \quad (x_{11}+x_{12}+x_{13}+x_{14}) \le 1$ (85)

Demand from *commune* 2 for project $j \quad (x_{21}+x_{22}+x_{23}+x_{24}) \le 1$ (86)

Demand from *commune* 3 for project $j \quad (x_{31}+x_{32}+x_{33}+x_{34}) \le 1$ (87)

Demand from *commune* 4 for project $j \quad (x_{41}+x_{42}+x_{43}+x_{44}) \le 1$ (88)

Demand from *commune* 5 for project $j \quad (x_{51}+x_{52}+x_{53}+x_{54}) \le 1$ (89)

Demand from *commune* 6 for project $j \quad (x_{61}+x_{62}+x_{63}+x_{64}) \le 1$ (90)

Demand from *commune* 7 for project $j \quad (x_{71}+x_{72}+x_{73}+x_{74}) \le 1$ (91)

Demand from *commune* 8 for project $j \quad (x_{81}+x_{82}+x_{83}+x_{84}) \le 1$ (92)

Demand from *commune* 9 for project $j \quad (x_{91}+x_{92}+x_{93}+x_{94}) \le 1$ (93)

Demand from *commune* 10 for project $j \quad (x_{101}+x_{102}+x_{103}+x_{104}) \le 1$ (94)

Demand from *commune* 11 for project $j \quad (x_{111}+x_{112}+x_{113}+x_{114}) \le 1$ (95)

Demand from *commune* 12 for project $j \quad (x_{121}+x_{122}+x_{123}+x_{124}) \le 1$ (96)

Demand from *commune* 13 for project $j \quad (x_{131}+x_{132}+x_{133}+x_{134}) \le 1$ (97)

Demand from *commune* 14 for project $j \quad (x_{141}+x_{142}+x_{143}+x_{144}) \le 1$ (98)

Demand from *commune* 15 for project $j \quad (x_{151}+x_{152}+x_{153}+x_{154}) \le 1$ (99)

Demand from *commune* 16 for project $j \quad (x_{161}+x_{162}+x_{163}+x_{164}) \le 1$ (100)

Demand from *commune* 17 for project j $(x_{171} + x_{172} + x_{173} + x_{174}) \le 1$ (101)

Demand from *commune* 18 for project j $(x_{181} + x_{182} + x_{183} + x_{184}) \le 1$ (102)

Demand from *commune* 19 for project j $(x_{191} + x_{192} + x_{193} + x_{194}) \le 1$ (103)

Demand from *commune* 20 for project j $(x_{201} + x_{202} + x_{203} + x_{204}) \le 1$ (104)

Demand from *commune* 21 for project j $(x_{211} + x_{212} + x_{213} + x_{214}) \le 1$ (105)

Demand from *commune* 22 for project j $(x_{221} + x_{222} + x_{223} + x_{224}) \le 1$ (106)

Demand from *commune* 23 for project j $(x_{231} + x_{232} + x_{233} + x_{234}) \le 1$ (107)

Demand from *commune* 24 for project j $(x_{241} + x_{242} + x_{243} + x_{244}) \le 1$ (108)

Demand from *commune* 25 for project j $(x_{251} + x_{252} + x_{253} + x_{254}) \le 1$ (109)

Demand from *commune* 26 for project j $(x_{261} + x_{262} + x_{263} + x_{264}) \le 1$ (110)

Demand from *commune* 27 for project j $(x_{271} + x_{272} + x_{273} + x_{274}) \le 1$ (111)

Demand from *commune* 28 for project j $(x_{281} + x_{282} + x_{283} + x_{284}) \le 1$ (112)

Demand from *commune* 29 for project j $(x_{291} + x_{292} + x_{293} + x_{294}) \le 1$ (113)

Demand from *commune* 30 for project j $(x_{301} + x_{302} + x_{303} + x_{304}) \le 1$ (114)

Demand from *commune* 31 for project j $(x_{311} + x_{312} + x_{313} + x_{314}) \le 1$ (115)

Demand from *commune* 32 for project j $(x_{321} + x_{322} + x_{323} + x_{324}) \le 1$ (116)

Demand from *commune* 33 for project j $(x_{331} + x_{332} + x_{333} + x_{334}) \le 1$ (117)

Demand from *commune* 34 for project j $(x_{341} + x_{342} + x_{343} + x_{344}) \le 1$ (118)

Demand from *commune* 35 for project j $(x_{351} + x_{352} + x_{353} + x_{354}) \le 1$ (119)

Demand from *commune* 36 for project j $(x_{361} + x_{362} + x_{363} + x_{364}) \le 1$ (120)

Demand from *commune* 37 for project j $(x_{371} + x_{372} + x_{373} + x_{374}) \le 1$ (121)

Demand from *commune* 38 for project j $(x_{381} + x_{382} + x_{383} + x_{384}) \le 1$ (122)

Demand from *commune* 39 for project j $(x_{391} + x_{392} + x_{393} + x_{394}) \le 1$ (123)

Demand from *commune* 40 for project j $(x_{401} + x_{402} + x_{403} + x_{404}) \le 1$ (124)

Demand from *commune* 41 for project j $(x_{411} + x_{412} + x_{413} + x_{414}) \le 1$ (125)

Demand from *commune* 42 for project j $(x_{421} + x_{422} + x_{423} + x_{424}) \le 1$ (126)

Demand from *commune* 43 for project j $(x_{431} + x_{432} + x_{433} + x_{434}) \le 1$ (127)

Demand from *commune* 44 for project j $(x_{441} + x_{442} + x_{443} + x_{444}) \le 1$ (128)

Demand from *commune* 45 for project j $(x_{451} + x_{452} + x_{453} + x_{454}) \le 1$ (129)

Demand from *commune* 46 for project j $(x_{461} + x_{462} + x_{463} + x_{464}) \le 1$ (130)

Demand from *commune* 47 for project j $(x_{471} + x_{472} + x_{473} + x_{474}) \le 1$ (131)

Equations 132 to 139 are “brute” demand constraints that assign at least one project j to each of the following high threat communes: 7, 9, 10, 15, 17, 20, 24, and 32.

$$\sum_{j=1}^{4} x_{7j} \geq 1 \tag{132}$$

$$\sum_{j=1}^{4} x_{9j} \geq 1 \tag{133}$$

$$\sum_{j=1}^{4} x_{10j} \geq 1 \tag{134}$$

$$\sum_{j=1}^{4} x_{15j} \geq 1 \tag{135}$$

$$\sum_{j=1}^{4} x_{17j} \geq 1 \tag{136}$$

$$\sum_{j=1}^{4} x_{20j} \geq 1 \tag{137}$$

$$\sum_{j=1}^{4} x_{24j} \geq 1 \tag{138}$$

$$\sum_{j=1}^{4} x_{32j} \geq 1 \tag{139}$$

Equation 140 is a binary constraint, which forces the analyst to select or reject (1 or 0) the assignment of a project *j* to a commune *i*.

$$x_{ij} = 1 \text{ or } 0 \ \ (\text{for all } i \text{ and } j) \tag{140}$$

APPENDIX G. DETAILED SETUP OF MODEL II

This Appendix outlines the detail calculations for Chapter VI, Section C.

A. SETS AND INDICES IN DETAIL

Let c'_i be the quality score for each commune *i*; where

$$c'_i \in [0,8] \text{ and } i = \{1,...,47\}$$

$$\alpha'_{qi} = \text{ quality score } q \text{ for commune } i$$

$$C'_i = \sum_{\forall q} \left(\frac{1}{2}\right) \alpha'_{qi}, \forall i + \sum_{k=1}^{K} \frac{1}{n_k} \sum_{j \in c_k} \frac{\alpha'_{qi}}{2} \tag{141}$$

$$n_k = \text{ number of } k \text{ in the subset of communes } i$$

Let p'_j be the quality score for each project *j*; where

$$p'_j \in \{7,8,9,10\} \text{ and } j = \{1,2,3,4\}$$

$$\begin{aligned} p'_1 &= 7 \\ p'_2 &= 8 \\ p'_3 &= 9 \\ p'_4 &= 10 \end{aligned} \tag{142}$$

For projects denoted as p'_1, 6 projects are available.

For projects denoted as p'_2, 8 projects are available.

For projects denoted as p'_3, 7 projects are available.

For projects denoted as p'_4, 3 projects are available.

In all, there are a total of 24 projects available.

B. COEFFICIENTS

Let Q_{ij} be the rehabilitation score, which is the difference between the quality scores for project *j* and commune *i*.

$$Q'_{ij} = (p'_j - c'_i) \in \mathbb{R}$$
$$\text{and} \quad i = \{1, ..., 47\},\ j = \{1, 2, 3, 4\} \tag{143}$$

C. DECISION VARIABLES

The optimization model uses x'_{ij} for its decision variables.

Let x'_{ij} be the binary decision variable,

$$\text{where } x'_{ij} = \begin{cases} 1 & \text{if project } p'_j \text{ is assigned to commune } i \\ 0 & \text{otherwise} \end{cases}$$
$$\text{and} \quad i = \{1, ..., 47\},\ j = \{1, 2, 3, 4\} \tag{144}$$

D. OBJECTIVE FUNCTION

The objective function maximizes the total value of rehabilitation.

$$Max' = \sum_{j=1}^{4} \sum_{i=1}^{47} Q'_{ij} x'_{ij} \tag{145}$$

E. CONSTRAINTS

Equations 146 to 149 are supply constraints ensuring that every project j is assigned to at most one commune i.

Supply of project $j = 1$, of which 6 are available

$$\begin{pmatrix} x'_{11} + x'_{21} + x'_{31} + x'_{41} + x'_{51} + x'_{61} + x'_{71} + x'_{81} + x'_{91} + x'_{101} + x'_{111} + x'_{121} + x'_{131} + \\ x'_{141} + x'_{151} + x'_{161} + x'_{171} + x'_{181} + x'_{191} + x'_{201} + x'_{211} + x'_{221} + x'_{231} + x'_{241} + x'_{251} + \\ x'_{261} + x'_{271} + x'_{281} + x'_{291} + x'_{301} + x'_{311} + x'_{321} + x'_{331} + x'_{341} + x'_{351} + x'_{361} + x'_{371} + \\ x'_{381} + x'_{391} + x'_{401} + x'_{411} + x'_{421} + x'_{431} + x'_{441} + x'_{451} + x'_{461} + x'_{471} \end{pmatrix} = 6 \tag{146}$$

Supply of project $j = 2$, of which 8 are available

$$\begin{pmatrix} x'_{12} + x'_{22} + x'_{32} + x'_{42} + x'_{52} + x'_{62} + x'_{72} + x'_{82} + x'_{92} + x'_{102} + x'_{112} + x'_{122} + x'_{132} + \\ x'_{142} + x'_{152} + x'_{162} + x'_{172} + x'_{182} + x'_{192} + x'_{202} + x'_{212} + x'_{222} + x'_{232} + x'_{242} + x'_{252} + \\ x'_{262} + x'_{272} + x'_{282} + x'_{292} + x'_{302} + x'_{312} + x'_{322} + x'_{332} + x'_{342} + x'_{352} + x'_{362} + x'_{372} + \\ x'_{382} + x'_{392} + x'_{402} + x'_{412} + x'_{422} + x'_{432} + x'_{442} + x'_{452} + x'_{462} + x'_{472} \end{pmatrix} = 8 \tag{147}$$

Supply of project $j = 3,$ of which 7 are available

$$\begin{pmatrix} x'_{13}+x'_{23}+x'_{33}+x'_{43}+x'_{53}+x'_{63}+x'_{73}+x'_{83}+x'_{93}+x'_{103}+x'_{113}+x'_{123}+x'_{133}+ \\ x'_{143}+x'_{153}+x'_{163}+x'_{173}+x'_{183}+x'_{193}+x'_{203}+x'_{213}+x'_{223}+x'_{233}+x'_{243}+x'_{253}+ \\ x'_{263}+x'_{273}+x'_{283}+x'_{293}+x'_{303}+x'_{313}+x'_{323}+x'_{333}+x'_{343}+x'_{353}+x'_{363}+x'_{373}+ \\ x'_{383}+x'_{393}+x'_{403}+x'_{413}+x'_{423}+x'_{433}+x'_{443}+x'_{453}+x'_{463}+x'_{473} \end{pmatrix} = 7 \quad (148)$$

Supply of project $j = 4,$ of which 3 are available

$$\begin{pmatrix} x'_{14}+x'_{24}+x'_{34}+x'_{44}+x'_{54}+x'_{64}+x'_{74}+x'_{84}+x'_{94}+x'_{104}+x'_{114}+x'_{124}+x'_{134}+ \\ x'_{144}+x'_{154}+x'_{164}+x'_{174}+x'_{184}+x'_{194}+x'_{204}+x'_{214}+x'_{224}+x'_{234}+x'_{244}+x'_{254}+ \\ x'_{264}+x'_{274}+x'_{284}+x'_{294}+x'_{304}+x'_{314}+x'_{324}+x'_{334}+x'_{344}+x'_{354}+x'_{364}+x'_{374}+ \\ x'_{384}+x'_{394}+x'_{404}+x'_{414}+x'_{424}+x'_{434}+x'_{444}+x'_{454}+x'_{464}+x'_{474} \end{pmatrix} = 3 \quad (149)$$

Equations 150 to 196 are demand constraints ensuring that every commune *i* receives at most one project *j*.

Demand from *commune* 1 for project *j* $(x'_{11}+x'_{12}+x'_{13}+x'_{14}) \le 1$ (150)

Demand from *commune* 2 for project *j* $(x'_{21}+x'_{22}+x'_{23}+x'_{24}) \le 1$ (151)

Demand from *commune* 3 for project *j* $(x'_{31}+x'_{32}+x'_{33}+x'_{34}) \le 1$ (152)

Demand from *commune* 4 for project *j* $(x'_{41}+x'_{42}+x'_{43}+x'_{44}) \le 1$ (153)

Demand from *commune* 5 for project *j* $(x'_{51}+x'_{52}+x'_{53}+x'_{54}) \le 1$ (154)

Demand from *commune* 6 for project *j* $(x'_{61}+x'_{62}+x'_{63}+x'_{64}) \le 1$ (155)

Demand from *commune* 7 for project *j* $(x'_{71}+x'_{72}+x'_{73}+x'_{74}) \le 1$ (156)

Demand from *commune* 8 for project *j* $(x'_{81}+x'_{82}+x'_{83}+x'_{84}) \le 1$ (157)

Demand from *commune* 9 for project *j* $(x'_{91}+x'_{92}+x'_{93}+x'_{94}) \le 1$ (158)

Demand from *commune* 10 for project *j* $(x'_{101}+x'_{102}+x'_{103}+x'_{104}) \le 1$ (159)

Demand from *commune* 11 for project *j* $(x'_{111}+x'_{112}+x'_{113}+x'_{114}) \le 1$ (160)

Demand from *commune* 12 for project *j* $(x'_{121}+x'_{122}+x'_{123}+x'_{124}) \le 1$ (161)

Demand from *commune* 13 for project *j* $(x'_{131}+x'_{132}+x'_{133}+x'_{134}) \le 1$ (162)

Demand from *commune* 14 for project *j* $(x'_{141}+x'_{142}+x'_{143}+x'_{144}) \le 1$ (163)

Demand from *commune* 15 for project *j* $(x'_{151}+x'_{152}+x'_{153}+x'_{154}) \le 1$ (164)

Demand from *commune* 16 for project *j* $(x'_{161}+x'_{162}+x'_{163}+x'_{164}) \le 1$ (165)

Demand from *commune* 17 for project *j* $(x'_{171}+x'_{172}+x'_{173}+x'_{174}) \le 1$ (166)

Demand from *commune* 18 for project *j* $(x'_{181}+x'_{182}+x'_{183}+x'_{184}) \le 1$ (167)

Demand from *commune* 19 for project *j* $(x'_{191}+x'_{192}+x'_{193}+x'_{194}) \le 1$ (168)

Demand from *commune* 20 for project *j* $(x'_{201}+x'_{202}+x'_{203}+x'_{204}) \le 1$ (169)

Demand from *commune* 21 for project *j* $(x'_{211}+x'_{212}+x'_{213}+x'_{214}) \le 1$ (170)

Demand from *commune* 22 for project j $(x'_{221}+x'_{222}+x'_{223}+x'_{224}) \leq 1$ (171)

Demand from *commune* 23 for project j $(x'_{231}+x'_{232}+x'_{233}+x'_{234}) \leq 1$ (172)

Demand from *commune* 24 for project j $(x'_{241}+x'_{242}+x'_{243}+x'_{244}) \leq 1$ (173)

Demand from *commune* 25 for project j $(x'_{251}+x'_{252}+x'_{253}+x'_{254}) \leq 1$ (174)

Demand from *commune* 26 for project j $(x'_{261}+x'_{262}+x'_{263}+x'_{264}) \leq 1$ (175)

Demand from *commune* 27 for project j $(x'_{271}+x'_{272}+x'_{273}+x'_{274}) \leq 1$ (176)

Demand from *commune* 28 for project j $(x'_{281}+x'_{282}+x'_{283}+x'_{284}) \leq 1$ (177)

Demand from *commune* 29 for project j $(x'_{291}+x'_{292}+x'_{293}+x'_{294}) \leq 1$ (178)

Demand from *commune* 30 for project j $(x'_{301}+x'_{302}+x'_{303}+x'_{304}) \leq 1$ (179)

Demand from *commune* 31 for project j $(x'_{311}+x'_{312}+x'_{313}+x'_{314}) \leq 1$ (180)

Demand from *commune* 32 for project j $(x'_{321}+x'_{322}+x'_{323}+x'_{324}) \leq 1$ (181)

Demand from *commune* 33 for project j $(x'_{331}+x'_{332}+x'_{333}+x'_{334}) \leq 1$ (182)

Demand from *commune* 34 for project j $(x'_{341}+x'_{342}+x'_{343}+x'_{344}) \leq 1$ (183)

Demand from *commune* 35 for project j $(x'_{351}+x'_{352}+x'_{353}+x'_{354}) \leq 1$ (184)

Demand from *commune* 36 for project j $(x'_{361}+x'_{362}+x'_{363}+x'_{364}) \leq 1$ (185)

Demand from *commune* 37 for project j $(x'_{371}+x'_{372}+x'_{373}+x'_{374}) \leq 1$ (186)

Demand from *commune* 38 for project j $(x'_{381}+x'_{382}+x'_{383}+x'_{384}) \leq 1$ (187)

Demand from *commune* 39 for project j $(x'_{391}+x'_{392}+x'_{393}+x'_{394}) \leq 1$ (188)

Demand from *commune* 40 for project j $(x'_{401}+x'_{402}+x'_{403}+x'_{404}) \leq 1$ (189)

Demand from *commune* 41 for project j $(x'_{411}+x'_{412}+x'_{413}+x'_{414}) \leq 1$ (190)

Demand from *commune* 42 for project j $(x'_{421}+x'_{422}+x'_{423}+x'_{424}) \leq 1$ (191)

Demand from *commune* 43 for project j $(x'_{431}+x'_{432}+x'_{433}+x'_{434}) \leq 1$ (192)

Demand from *commune* 44 for project j $(x'_{441}+x'_{442}+x'_{443}+x'_{444}) \leq 1$ (193)

Demand from *commune* 45 for project j $(x'_{451}+x'_{452}+x'_{453}+x'_{454}) \leq 1$ (194)

Demand from *commune* 46 for project j $(x'_{461}+x'_{462}+x'_{463}+x'_{464}) \leq 1$ (195)

Demand from *commune* 47 for project j $(x'_{471}+x'_{472}+x'_{473}+x'_{474}) \leq 1$ (196)

Equations 197 to 204 are "brute" demand constraints that assign at least one project j to each of the following high threat communes: 7, 9, 10, 15, 17, 20, 24, and 32.

$$\sum_{j=1}^{4} x'_{7j} \geq 1 \tag{197}$$

$$\sum_{j=1}^{4} x'_{9j} \geq 1 \tag{198}$$

$$\sum_{j=1}^{4} x'_{10j} \geq 1 \tag{199}$$

$$\sum_{j=1}^{4} x'_{15j} \geq 1 \tag{200}$$

$$\sum_{j=1}^{4} x'_{17j} \geq 1 \tag{201}$$

$$\sum_{j=1}^{4} x'_{20j} \geq 1 \tag{202}$$

$$\sum_{j=1}^{4} x'_{24j} \geq 1 \tag{203}$$

$$\sum_{j=1}^{4} x'_{32j} \geq 1 \tag{204}$$

Equation 205 is a binary constraint, which forces the analyst to select or reject (1 or 0) the assignment of a project j to a commune i.

$$x'_{ij} = 1 \text{ or } 0 \quad (\text{for all } i \text{ and } j) \tag{205}$$

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APPENDIX H. COMPUTER ANALYSES

A. SETUP IN MICROSOFT EXCEL WITH RISK SOLVER PLATFORM

Frontline Systems' Risk-Solver Platform (RSP) add-in tool allows the decision analyst to handle conventional optimization, simulation optimization, and stochastic optimization problems.[148] Additionally, the analyst can perform predictive and prescriptive analytics, while handling up to 8,000 decision variables (40 times larger than the Excel Solver) by using one of the seven built-in advanced Solver engines (e.g., LP/Quadratic, SOCP Barrier, Interval Global and Evolutionary Solvers).[149] Decision analysts have the ability to find better solutions to leverage better optimization algorithms and the advanced PSI Interpreter (or The Polymorphic Spreadsheet Interpreter). The PSI interpreter analyzes the model in many ways not possible with the Excel recalculator:[150]

1. Analysts can diagnose the model as an LP, quadratic programming, smooth nonlinear, or non-smooth optimization model, and automatically select Solver engines suitable for the model. In addition, it pinpoints formulas that make the model nonlinear or non-smooth.
2. Analysts can compute derivatives of the problem functions directly, using the methods of automatic differentiation, which is faster and more accurate than the method of formula recalculation and "finite differencing" used by the Excel Solver and Premium Solver.
3. Analysts can compute interval values for Excel formulas in the model, in addition to simple numeric values, which the Interval Global Solver uses to find globally optimal solutions to optimization problems

B. MODEL I: RSP SETUP AND RESULTS

See Table 19 for the RSP Excel setup of Model I.[151]

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[148] Frontline Systems, *FrontlineSolvers: Risk Solver Platform Add-In* (Incline Village, NV: Frontline Systems, 2013) http://www.solver.com/risk–solver–platform.

[149] Ibid.

[150] Ibid.

[151] The author hid the decision variable and constraint cells for readability.

Table 19. Model I: “Set Covering” Risk Solver Platform

EQ#

1

$$c_i = \sum_{j=1}^{4} \alpha_{ij}$$

α_{ij} = quality score j for commune i

2

$p_j \in \{7,8,9,10\}$ and $j = \{1,2,3,4\}$

3

$$Q_{ij} = (p_j - c_i) \in \mathbb{R}$$

and $i = \{1,\ldots,47\}$, $j = \{1,2,3,4\}$

4

where $x_{ij} = \begin{cases} 1 & \text{if project } p_j \text{ is assigned to commune } i \\ 0 & \text{otherwise} \end{cases}$

and $i = \{1,\ldots,47\}$, $j = \{1,2,3,4\}$

5

$$Z = \sum_{j=1}^{4} \sum_{i=1}^{47} Q_{ij} x_{ij}$$

Row	A	B	AE	AG	AH	AK	AN	AS	BF	BI	BM	BN	BO	CA	CJ	CQ	CU	CY	DC	DG	DL	DP	EG	EQ	EW	FX	GI	GJ	GK	GL
14			Q_{291}	Q_{311}	Q_{321}	Q_{351}	Q_{381}	Q_{431}	Q_{92}	Q_{122}	Q_{162}	Q_{172}	Q_{182}	Q_{302}	Q_{392}	Q_{462}	Q_{33}	Q_{73}	Q_{113}	Q_{153}	Q_{203}	Q_{243}	Q_{413}	Q_{44}	Q_{104}	Q_{374}				
15		***Coefficients***	2.00	1.25	2.00	1.25	1.50	2.00	3.00	3.25	2.25	2.25	2.25	3.25	2.50	3.00	3.50	4.25	5.25	5.25	4.50	4.50	6.75	6.00	5.75	5.75	**83.25**	Tot Max Rehab		
21			x_{291}	x_{311}	x_{321}	x_{351}	x_{381}	x_{431}	x_{92}	x_{122}	x_{162}	x_{172}	x_{182}	x_{302}	x_{392}	x_{462}	x_{33}	x_{73}	x_{113}	x_{153}	x_{203}	x_{243}	x_{413}	x_{44}	x_{104}	x_{374}				
22		***Decision Variables***	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**24**	Tot Alloc Proj		
29	EQ#	***Constraints***																									LHS	sign	RHS	EQ#
30	6	Covering c1			1											1											2	≥	1	6
76	52	Covering c47														1											1	≥	1	52
77	53	Supply x_{i1}	1	1	1	1	1	1																			6	=	6	53
78	54	Supply x_{i2}							1	1	1	1	1	1	1	1											8	=	8	54
79	55	Supply x_{i3}															1	1	1	1	1	1	1				7	=	7	55
80	56	Supply x_{i4}																						1	1	1	3	=	3	56
81	57	Demand x_{1j}																									0	≤	1	57
127	103	Demand x_{47j}																									0	≤	1	103
128	104	High Threat x_{7j}																1									1	≥	1	104
129	105	High Threat x_{9j}							1																		1	≥	1	105
130	106	High Threat x_{10j}																							1		1	≥	1	106
131	107	High Threat x_{15j}																		1							1	≥	1	107
132	108	High Threat x_{17j}										1															1	≥	1	108
133	109	High Threat x_{20j}																			1						1	≥	1	109
134	110	High Threat x_{24j}																				1					1	≥	1	110
135	111	High Threat x_{32j}			1																						1	≥	1	111

See Figure 39 for the Risk Solver Platform model specifications for Model I.

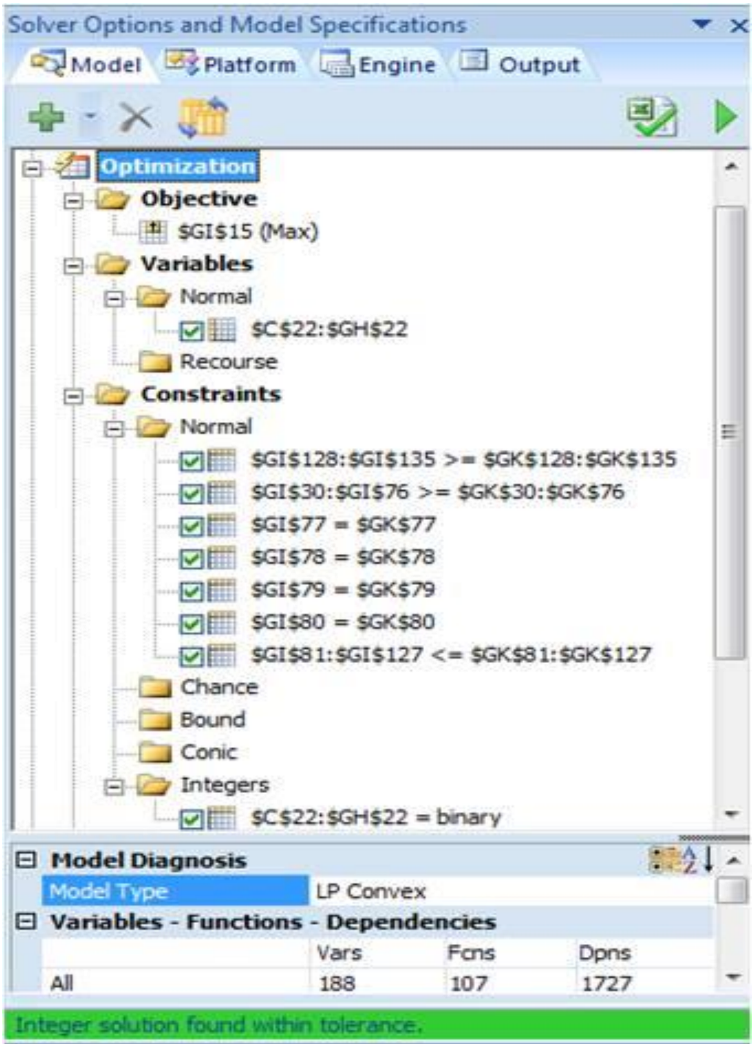

Figure 39. Risk Solver Platform Model Specifications: Model I[152]

The Risk Solver Platform Solver add-in used the "Standard LP/Quadratic Engine" to solve for an optimal allocation of rehabilitation based on rehabilitation scores. Also, RSP conducted an automated test for convexity and diagnosed the model as LP Convex. Geometrically, the constraints and objective function are convex, because line segments could be drawn from point(s) (x, $f(x)$) to other point(s) (y, $f(y)$).

[152] Frontline Systems, "Large-Scale LP/QP Solver Engine," Frontline Systems.

See Figure 40 for the RSP output, which outlines RSP's diagnosis of Model I.

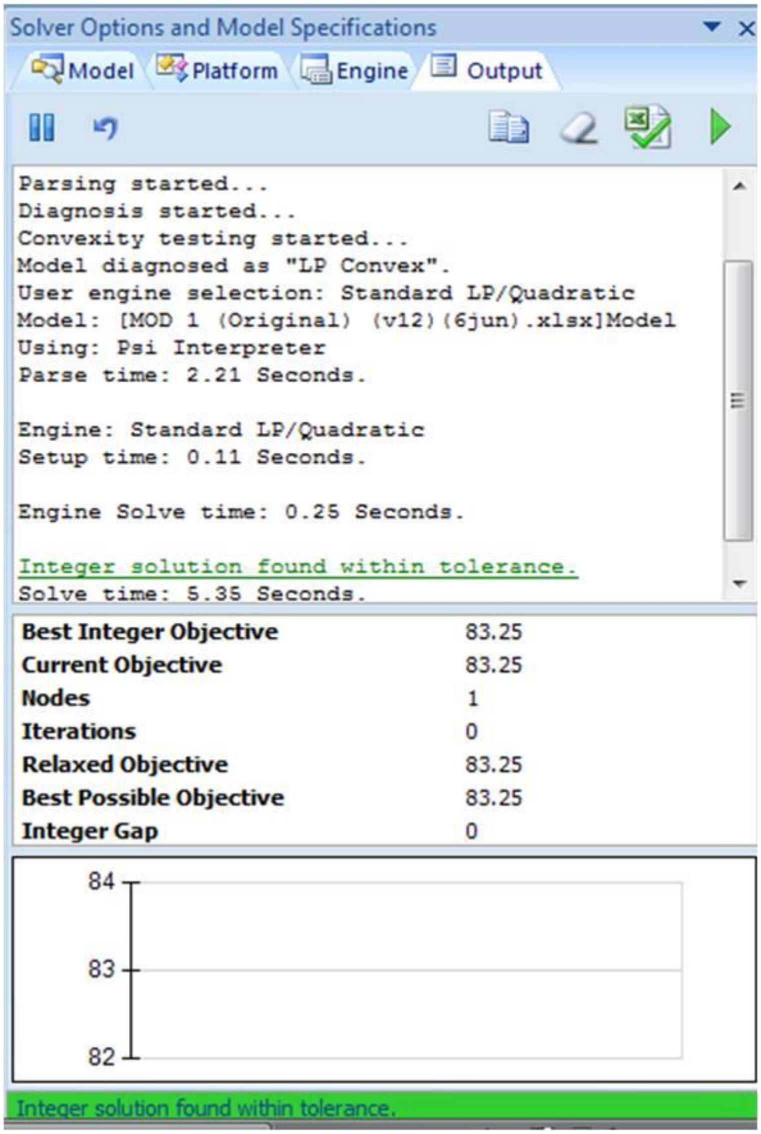

Figure 40. Risk Solver Platform Output: Model I[153]

C. MODEL II: RSP SETUP AND RESULTS

See Table 20 for the Risk Solver Platform Excel setup for Model II.

153 Ibid.

Table 20. Model II: “Realm of Influence” Risk Solver Platform

EQ#

114
$$c'_i = \sum_{j=1}^{5}\left(\frac{1}{2}\right)\alpha'_{ij} + \sum_{k=1}^{K}\left(\frac{1}{2*n_k}\right)c_k$$

$\alpha'_{ij} =$ quality score j for commune i

$c_k =$ discrete subset of communes i, which are adjacent to c'_i

$n_k =$ number of k in the subset of communes i

115
$$p'_j \in \{7,8,9,10\} \quad \text{and} \quad j = \{1,2,3,4\}$$

116
$$Q'_{ij} = (p'_j - c'_i) \in \mathbb{R}$$
$$\text{and} \quad i = \{1,\ldots,47\},\ j = \{1,2,3,4\}$$

Row	A	B	S	V	Z	AH	AM	AS	BF	BG	BI	BK	BL	BR	CF	CL	CS	CY	DC	DH	DQ	DT	DU	FT	FY	FZ	GI	GJ
17			Q'_{171}	Q'_{201}	Q'_{241}	Q'_{321}	Q'_{371}	Q'_{431}	Q'_{92}	Q'_{102}	Q'_{122}	Q'_{142}	Q'_{152}	Q'_{212}	Q'_{352}	Q'_{412}	Q'_{13}	Q'_{73}	Q'_{113}	Q'_{163}	Q'_{253}	Q'_{283}	Q'_{293}	Q'_{334}	Q'_{384}	Q'_{394}		
18		*Coefficients*	2.47	0.73	1.50	0.90	3.36	3.21	2.06	1.18	4.65	3.33	3.96	2.86	2.80	2.99	3.82	4.48	4.74	4.15	3.70	4.05	4.67	5.39	4.90	4.95	**80.87**	Tot Max Rehab

117
$$\text{where } x'_{ij} = \begin{cases} 1 & \text{if project } p'_j \text{ is assigned to commune } i \\ 0 & \text{otherwise} \end{cases}$$
$$\text{and} \quad i = \{1,\ldots,47\},\ j = \{1,2,3,4\}$$

Row	A	B	S	V	Z	AH	AM	AS	BF	BG	BI	BK	BL	BR	CF	CL	CS	CY	DC	DH	DQ	DT	DU	FT	FY	FZ	GI	GJ
24			x'_{171}	x'_{201}	x'_{241}	x'_{321}	x'_{371}	x'_{431}	x'_{92}	x'_{102}	x'_{122}	x'_{142}	x'_{152}	x'_{212}	x'_{352}	x'_{412}	x'_{13}	x'_{73}	x'_{113}	x'_{163}	x'_{253}	x'_{283}	x'_{293}	x'_{334}	x'_{384}	x'_{394}		
25		*Decision Variables*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**24**	Tot Alloc Proj

118
$$Z' = \sum_{j=1}^{4}\sum_{i=1}^{47} Q'_{ij}x'_{ij}$$

Row	EQ#	Constraints	S	V	Z	AH	AM	AS	BF	BG	BI	BK	BL	BR	CF	CL	CS	CY	DC	DH	DQ	DT	DU	FT	FY	FZ	LHS	sign	RHS	EQ#
80	166	Supply x'_{i1}	1	1	1	1	1	1																			6	=	6	166
81	167	Supply x'_{i2}							1	1	1	1	1	1	1	1											8	=	8	167
82	168	Supply x'_{i3}															1	1	1	1	1	1	1				7	=	7	168
83	169	Supply x'_{i4}																						1	1	1	3	=	3	169
84	170	Demand x'_{1j}															1										1	≤	1	170
130	216	Demand x'_{47j}																									0	≤	1	216
131	217	High Threat x'_{7j}																1									1	≥	1	217
132	218	High Threat x'_{9j}							1																		1	≥	1	218
133	219	High Threat x'_{10j}								1																	1	≥	1	219
134	220	High Threat x'_{15j}											1														1	≥	1	220
135	221	High Threat x'_{17j}	1																								1	≥	1	221
136	222	High Threat x'_{20j}		1																							1	≥	1	222
137	223	High Threat x'_{24j}			1																						1	≥	1	223
138	224	High Threat x'_{32j}				1																					1	≥	1	224

See Figure 41 for the Risk Solver Platform model specifications for Model II.

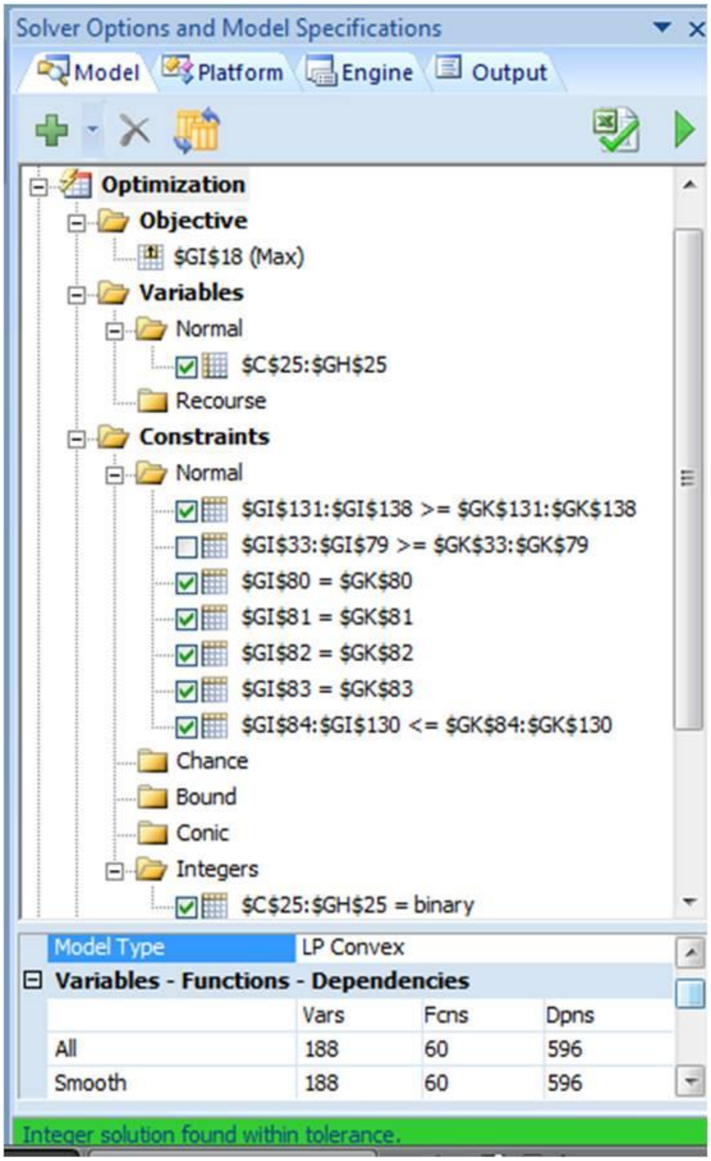

Figure 41. Risk Solver Platform Model Specifications: Model II[154]

154 Ibid.

See Figure 42 for the RSP output, which outlines RSP's diagnosis of the model for Model II.

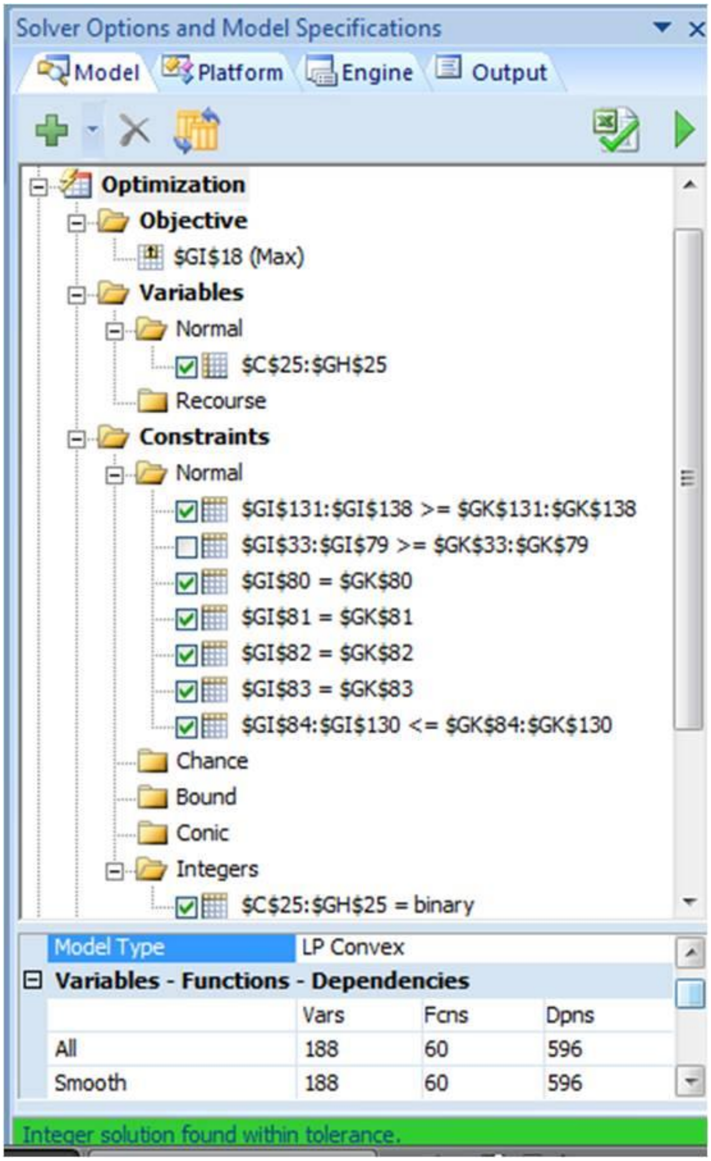

Figure 42. Risk Solver Platform Output for Model II[155]

155 Ibid.

Table 21 illustrates the upgradeable options that Frontline Solvers offers.

Table 21. Comparisons: Frontline Solver Upgrades to the Basic Solver[156]

	Basic Excel Solver	Risk Solver Platform
Product Scope:	• Conventional Optimization	• Conventional Optimization • Monte Carlo Simulation • Simulation Optimization • Stochastic Optimization
Platform:	Windows and Mac	Windows
Solve more types of problems:		
Solves LP, MIP, NLP, and NSP problem types	Yes	Yes
Additional solvers for QP, QCP, SOCP problem types		Yes
Solves simulation and simulation optimization problems		Yes
Supports recourse decisions under uncertainty		Yes
Solve larger problems:		
# of Linear decision variables	200	8000 (40x)
# of Nonlinear decision variables	200	1000 (5x)
# of Non-smooth decision variables	200	1000 (5x)
# of decisions variables with optional plug-in Solver engines		Millions
Get solutions in less time: *		
Linear problems	1x (LP)	40x (LP/QP)
Mixed Integer problems	1x (LP)	20x – 40x (LP/QP)
Non Linear problems	1x (GRG)	7x – 15x (LSGRG)
Non-smooth problems	1x	2x – 20x
Solution speed with optional plug-in solver engines		10x – 1000x
Model transformation for better answers more quickly		Yes
Handle a wider variety of constraints:		
Normal, integer, binary, and alldifferent	Yes	Yes
Semi-continuous		Yes
2nd order cone		Yes
Probabilistic and Chance		Yes
Get help and guidance along the way:		
Context sensitive help and included example models		Yes
Comprehensive charting, reporting, and sensitivity/scenario analysis		Yes
Guided Mode assistance built-in		Yes
Automatic Mode for model type analysis and selection of best engine		Yes

[156] Frontline Systems, *Comparisons: Frontline Solver Upgrades to the Basic Solver* (Incline Village, NV: Frontline Systems, 2014), http://www.solver.com/files/_document/Upgrader–Comparison–Chart.pdf.

APPENDIX I. AN INSPIRATION FOR MODELING CONSTRAINTS

After prototyping the BIP model during the embryonic stage of formulation, it seemed that the model resembled certain aspects of *wéiqí*. *Wéiqí* or "Go" is a two-player board game (usually with a 19×19 grid), laden with tactics and strategy, which originated in ancient China more than two millennia ago. Although the situation in Mali is a multiple n-player game of state actors, international organizations, private organizations, and non-state actors, the finer points of strategy and tactics are the most interesting aspects of *wéiqí* that this thesis focuses on to derive various algorithms and constraints.

The goal of *wéiqí* is for a player to place his stones (black or white stones) to envelop a greater total area of the board than the opposing player. As the players alternately place their stones on the board, the stones may not move, unless the opposing player captures it. Movement is nonlinear (that is, a stone may be placed almost anywhere on the board on any move). To capture an opponent's stones, a player must surround an opposing stone or group of stones by creating a cordon or occupying every orthogonally-adjacent intersection (i.e., a set of mutually perpendicular axes). The players continue playing in this fashion until both players decide to quite playing or making subsequent moves.

Similar to the real world, *wéiqí* does not have a set condition for the endgame. Unless a player yields, the player with the most points wins the game. To tally the score, the following scoring takes place: (1) a count of controlled territory (or intersections), (2) the number of captured stones, and (3) the white stone handicap (known as *komi*) of points added to the white player's score. Strategy, not scoring, is the take away.

Wéiqí is a reminder of why leaders must develop strategy and policy to account for global influence. While keeping the entire board in mind, during the tactical and operational level fighting, decision makers must always maintain a strategic advantage, even if it means a tactical loss. The most basic maxim of *wéiqí* is optimizing the number of courses of action remaining for a stone or group of stones, after a tactical level conflict has occurred, called a_{ij}. The notion of a_{ij} must inspire every maneuver and course of action. A decision analyst owes it to a decision maker to answer the question: do I still have a_{ij} with this move and what are the cascading effects of future move with residual a_{ij}? Figure 43 serves as a visual representation of the *wéiqí* board with stones, which motivated the use of IP modeling to operationalize the conflict.

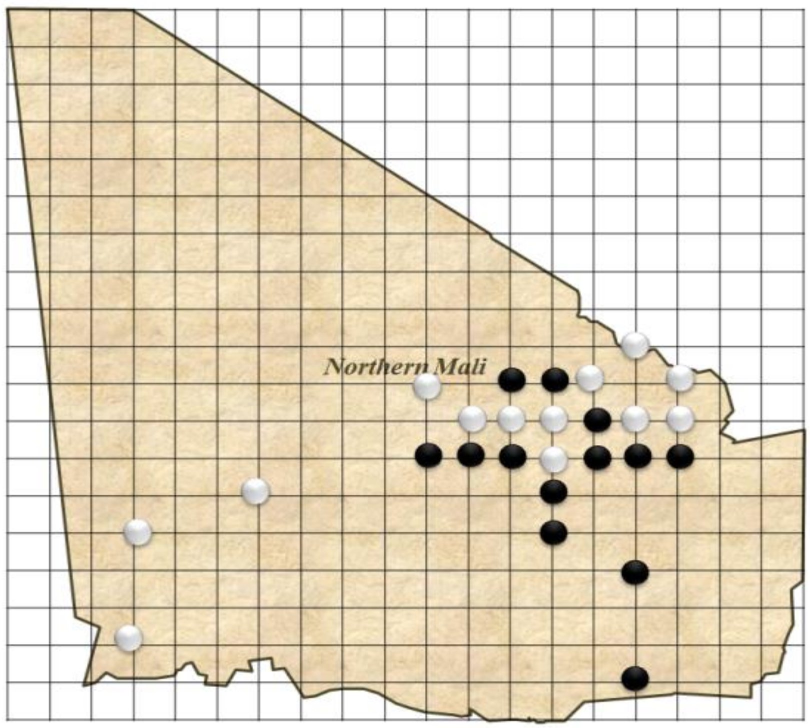

Figure 43. *Wéiqí* or "Go": A Two-Player Board Game

Like irregular warfare, *wéiqí* is difficult to learn and execute well. Novices who do not appreciate the subtleties and nuances of the minor concepts of the game will suffer as the game progresses. In that vein of inexperience, decision analysts owe it to decision makers to eliminate the rookie moves of randomly placing stones on the board, as if it were a probabilistic game of chance. Just as information, maneuver, and combat power advantages aid a player in irregular warfare, a weaker *wéiqí* player will eventually lose to the more experienced player who fashions optimal formations and appreciates the strategic placement and contiguous connections of stones for greater power. Ultimately, a superior *wéiqí* player understands the highly dynamic balance between power, control, territory, and influence.

APPENDIX J. THE PROBLEM IN NORTHERN MALI

A. A BRIEF LOOK AT THE HISTORY OF MALI

As with any problem, a decision analyst must consider the history and nature of the conflict. Analysts can go as far back as 300 A.D. or begin at the rise and fall of various Sahelian kingdoms. Although the Malinke ruled present-day Mali from the 12th through the 16th centuries, perhaps the more interesting starting point of Malian history would be the famed empires of the Sahel region. Mali was once part of the three legendary Sahelian empires that ruled the Sahel region and Trans Saharan trade routes. From the Ghana Empire to the Mali and Songhai Empires, the Sahelian people thrived from trade and the spread of Islam. More specifically, analysts can study the rule of the Songhai Empire's control of the Gao and Tombouctou regions and the events leading to the Moroccan invasion of Tombouctou.

However, to truly understand the deep-rooted sentiment that exists in Northern Mali today, analysts can choose to start with France's control in the late 19th century and subjugation of Mali in the early 1900s, the dubbing of the colony as French Sudan in 1920, membership of the French Union in the mid-1940s, or its independence from France in 1960. Since the 1960s, the Republic of Mali received aid from China, Russia, Europe, and other Western nations.

B. LESSONS LEARNED: CHINA'S SUCCESS

Learning from the Chinese experience in 1968 could be worthwhile. Although China briefly struggled with its influence over the region in the late 1960s, its well-placed surrogates guaranteed the influence it wields today. Learning how China maintained its influence even through the bloodless military coup in late 1968 would be worthwhile and highly relevant to the current state of affairs. Western nations can learn something from China's resiliency in maintaining its influence, while Mali transitioned from a dictatorship 1960 to 1968, military rule from 1968 to 1991, Democratic rule from 1992 to

2012, military coup d'état in 2012, and Democratic rule today. What did China do right that everyone else continually fails to do? If not China, can decision analysts learn from the successes of past Malian leaders?

C. LESSONS LEARNED: FORMER AFRICAN LEADERS

President Alpha Oumar Konaré, former democratic President of Mali and first Chairperson of the African Union Commission, is a relevant change agent who is certainly worth studying. President Konaré's political savvy began in the late 1960s, and his influence continued through the early 2000s. The military coup d'état and resultant 23-year military rule of President Konaré really shaped his political ideology. Starting out as the Secretary General of the Sudanese Union/African Democratic Rally (US-RDA) in 1967 and later becoming a staunch activist of Marxism-Leninism, due to the military coup d'état, decision analysts can learn about the ever changing dynamic of the region and various influences affecting Bamako politics in the national capital city of Mali. By 1990, President Konaré shifted to actively supporting a Democratic ideology called ADEMA (*Alliance pour la Démocratie en Mali*). Again, this significant shift from his activist days of supporting the clandestine Marxist-Leninist movement, known as the Malian Party for Work (PMT or *Parti malien du travail*), should give analyst an idea of the patience and understanding needed to operate in the Sahel region.

By 1992, President Konaré became Mali's first democratically elected president, and throughout his first and second terms, Mali's political and social stability served as a model for other African nations. However, in the early 1990s, President Konaré fought the Tuaregs due to a sentiment of lack of commonality with the black African majority, and political and cultural marginalization. Before the end of his first term, President Konaré ushered a peace accord with the Tuaregs in 1995, which resulted in thousands of Tuareg refugees returning to Northern Mali's desert region. By his second term, the international community was applauding President Konaré's efforts to revitalize Mali's economy, by increasing foreign investment and making Mali the one of largest cotton producers of Africa. Finally, as the chairman of the 15-nation, Economic Community of

West African States apparatus (ECOWAS), Western nations lauded President Konaré's peace brokering of the conflicts in the sub-Sahara (between Sierra Leone, Liberia, and Guinea).

Likewise, decision analysts should study the rise and fall of former President Amadou Toumani Touré who orchestrated the 1991 coup d'état freeing Mali from military rule and the subsequent coup d'état that led to his fall in 2012. What went wrong from the time that President Konaré signed the 1995 peace agreement to the 2006 rebellion and rebel activities that continue to persist? In June 2006, President Touré signed a peace agreement to end the Tuareg rebellion, and he guaranteed development and anti-poverty programs for Northern Mali. Within a year, the Tuaregs reconvened its rebel activities and began kidnapping soldiers. By early 2009, the Malian military regained controlled many Tuareg strongholds, which greatly reduced the Tuareg's ability to fight and displaced many of the rebels who turned to Libya. However, recognizing the Tuareg situation and sentiment, Muammar al-Qaddafi championed, armed, and equipped the Tuaregs for his personal force protection. Naturally the fall of al-Qaddafi led to the hasty return of the newly emboldened Tuareg fighters, but not before raiding arms and ammunition depots on their way back to their strongholds in Northern Mali.

D. CRISIS ACTION MODE: NOT LEARNING FROM HISTORY

After scoring key victories and decisively defeating and demoralizing the Malian defense force, the country's military overthrew the government, raided the presidential palace, and revoked the constitution. Within a matter of days, the rebels colluded with al-Qaida and its affiliates to seize most of the Northern Mali. Within weeks, the National Movement for the Liberation of Azawad (MNLA) rebels unilaterally declared their independence and declared the Independent State of the Azawad (which controls Tombouctou, Gao, Kidal, and pockets of Mopti). Why did Western nations believe that Mali was among the most stable democracies in Africa? What did President Touré do to lose the trust of the military that once revered him and later set the conditions for the rebels to gain decisive control of Northern Mali? If analysts can understand these basic questions, they can offer salient and meaningful recommendations to decision makers

E. THE AFTERMATH

Low- and mid-level soldiers, frustrated with the poor handling of the rebellion overthrew Toure on 22 March. Intensive mediation efforts led by the Economic Community of West African States (ECOWAS) returned power to a civilian administration in April with the appointment of interim President Dioncounda Traore. The post-coup chaos led to rebels expelling the Malian military from the three northern regions of the country and allowed Islamic militants to set up strongholds. Hundreds of thousands of northern Malians fled the violence to southern Mali and neighboring countries, exacerbating regional food insecurity in host communities. An international military intervention to retake the three northern regions began in January 2013 and within a month most of the north had been retaken. In a democratic presidential election conducted in July and August of 2013, Ibrahim Boubacar Keita was elected president in the second round. What actions should the U.S. and its allies take next? What does history tell us?

Figure 44 illustrates the aftermath of the military coup in Mali.

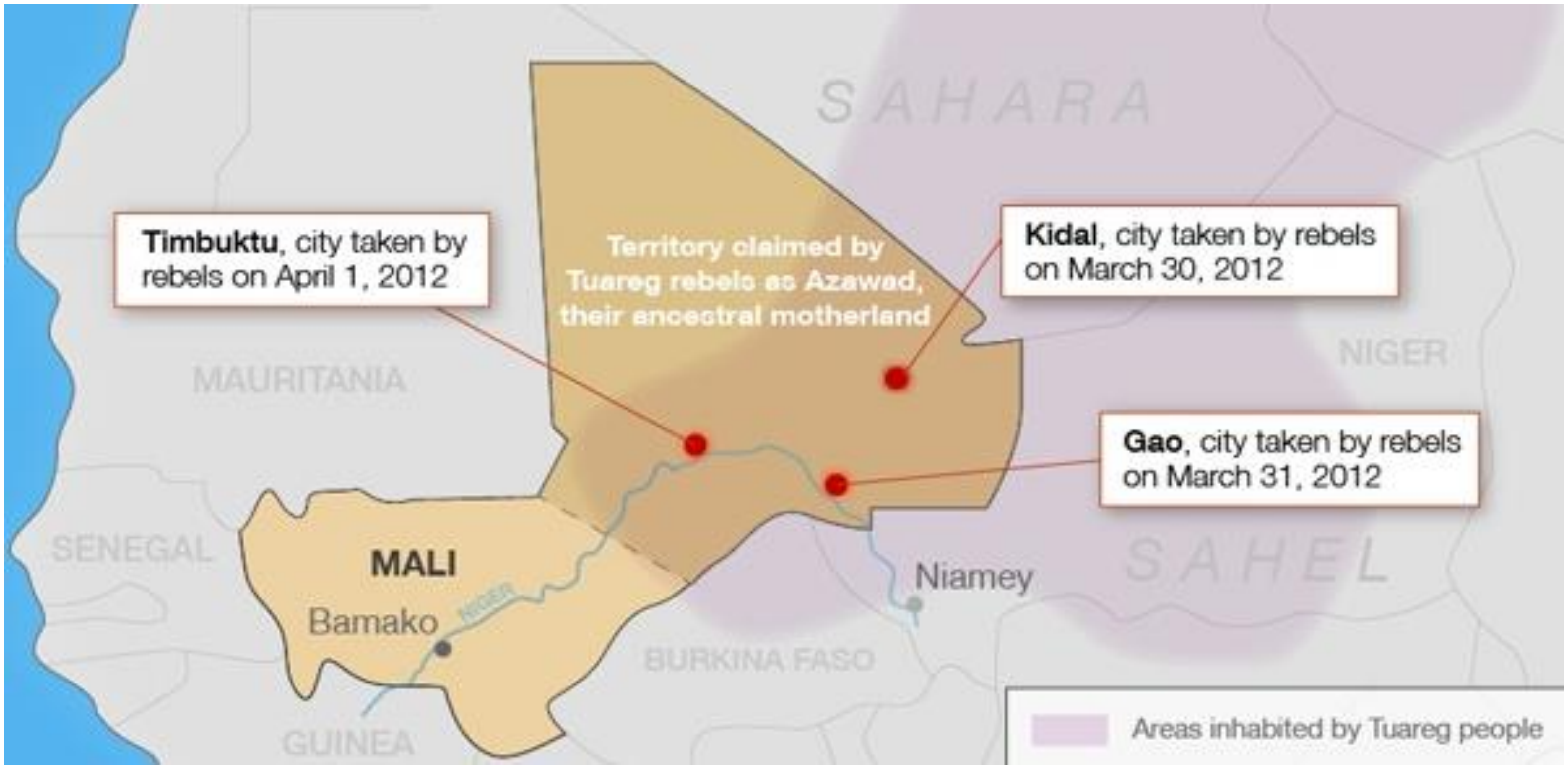

Figure 44. Aftermath of the Military Coup in Mali: 30 March to 01 April 2012[157]

157 Tom Hayden, "The Long War Reaches Mali," *The Huffington Post*, sec. Politics, December, 2012.

Figure 45 reflects the timeline of the events before and after the military coup d'état (October 2011 to January 2014).

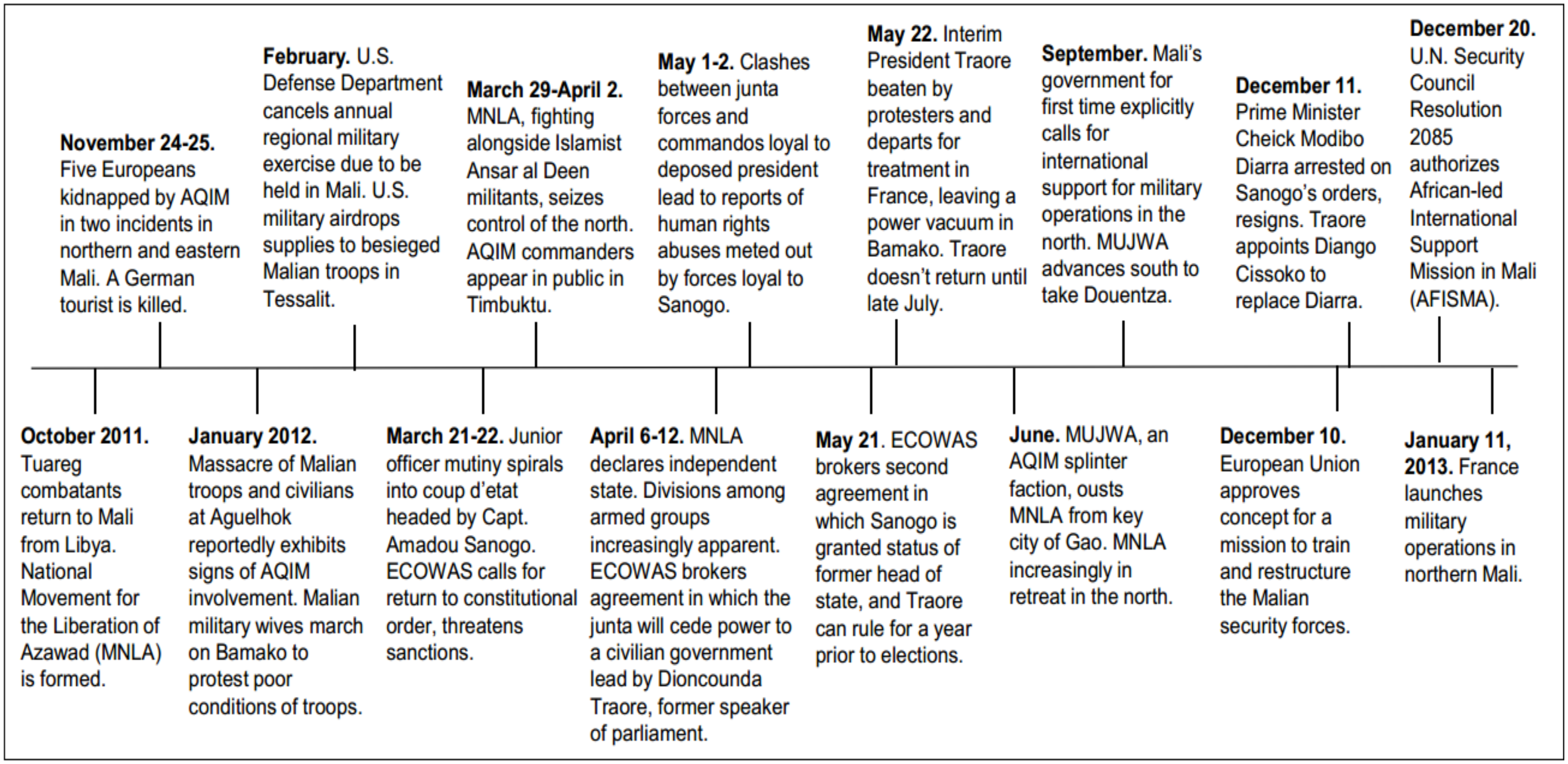

Figure 45. Mali: Timeline of Selected Recent Events[158]

158 Arieff, *Crisis in Mali*, 5.

APPENDIX K. THE DIRECT APPROACH

Agence France-Presse (AFP) illustrated the contributions of African and Western militaries in support of the French–Mali intervention in Northern Mali. As France leads counterterrorism operations, Western allies continue to offer limited logistics and transportation support while African regional security apparatuses provide direct support. Figure 46 illustrates CT operations as a direct approach, as discussed in the thesis.

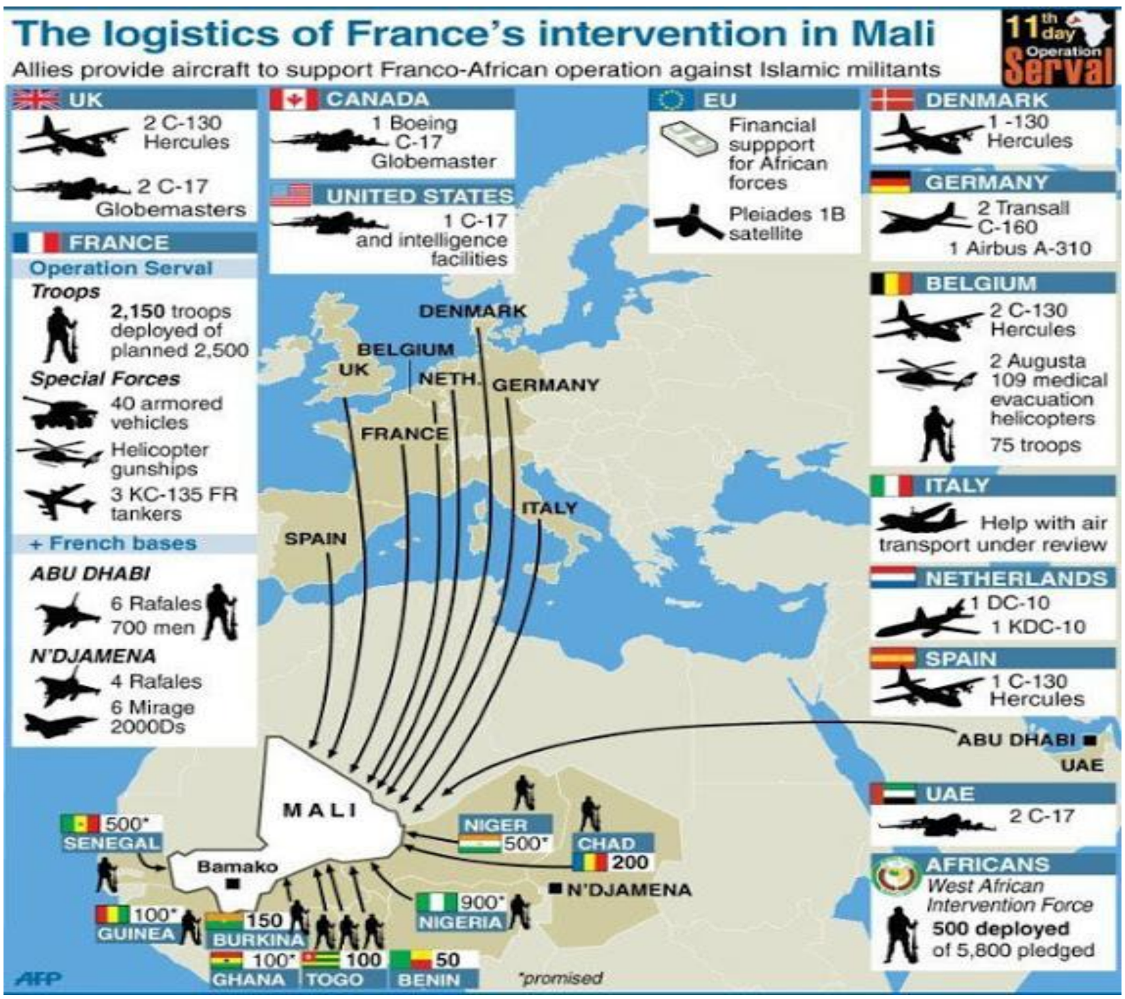

Figure 46. Direct Approach: Coalitions Supporting France in Mali[159]

159 Agence France-Presse, *Logistics of France's Intervention in Mali* (Paris, France: Agence France-Presse, 2013).

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